REMOTE SENSING EQUIPMENT FOR CHRONIC OIL DISCHARGES

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by

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SECTION 1

INTRODUCTION

With the recent hydrocarbon discoveries off Canada's east coast there has been a marked increase in petroleum activities. Exploration has been stepped up and activities related to production have commenced. The geographic area being considered extends from the Scotian Shelf to offshore Labrador with areas of concentration occurring near Sable Island and the North East Grand Banks. In the future, as drilling technology improves, simple extrapolation could increase the geographic area as far north as Lancaster Sound. The logistics involved in monitoring such a widespread area present great difficulties, increasing the requirement to monitor chronic and accidental pollutants released from offshore wellsites, production facilities and/or peripheral related activities.

To adequately monitor these types of discharge, the use of remote sensing technology offers promise. By its very nature, remote sensing is an adaptable technology, whether it be used with space platforms, from aircraft, or in surface mounted variations. The objective of this report is to present the results of an investigation conducted into the use of sensor systems mounted on ships, drilling rigs and/or related vessels. Sensing techniques and systems with the utility to monitor accidental and chronic discharges of oil or other drilling/production wastes emanating from typical sources are discussed. Recommendations are extrapolated regarding the identification of an appropriate sensing system useful for monitoring, countermeasures planning and potential future compliance monitoring.

1.1 Scope of Study

The purpose of this study was to document the capability of remote sensing systems to monitor chronic oil discharges. The investigation was limited to state-of-the-art equipment and techniques that have the potential for adaptation as vessel or rig mounted systems with routine monitoring capabilities. To accomplish this a comprehensive literature search was conducted, involving government, university, and research centres; including international documents, papers and reports. This information was documented and candidate sensor systems identified. The candidate sensors were quantified in terms of detection limits, sensing range, environmental restrictions, adaptability to rig or vessel mounting and operating limitations. The subsequent step was to evaluate the sensors in terms of operating scenarios where accidental or chronic oil and production waste discharges could occur. Based on these results, recommendations are extrapolated regarding sensor/technique utility for the following three categories:

1) operational
2) theoretically usable but untested
3) new technology with high potential.

The resulting, suitable sensor package and its installation are discussed. Appendix A provides a detailed scope of work listed by task. Appendix B presents an annotated bibliography of selected reports and papers reviewed for this study. Only those papers with a reasonable level of relevance are included.

1.2 Chronic and Accidental Oil Discharges

This report discusses the utility of remote sensing methodology, from surface based platforms, for the detection and monitoring of chronic or accidental oil discharges. Thus, a definition of the potential discharges and their related characteristics is presented.

A major or catastrophic spill, large in both area and volume, could occur from a blow-out or tanker accident. Methods of detection, monitoring and identification of this type of discharge are well documented and include both aircraft and satellite mounted sensors. This type of oil spill is not considered in this study.

This study is oriented towards those spills that are limited in both volume of pollutant and areal extent, and are virtually confined to the area directly around the source. These spills occur, and reoccur, at facilities where petroleum products are handled. They are most often accidental and minor in nature. They occur due to negligence, human and design errors, operation errors, and mechanical failures. Sources of concern include oil/water separators, spillover and slop from exploration rigs and drilling material debris. In addition, there is an increasing interest on the part of operators in the use of petroleum and mineral oil-based drilling muds in offshore exploration and development occurring off the east coast. Several trial uses of mineral oil-based muds have already been approved by regulatory agencies. Oil-based muds are used extensively in production drilling in some parts of the world.

When spills occur frequently and over an extended period of time, they are considered chronic. Although singularly, they have no significant impact on the environment, over time, their impact increases. The spill volumes of significance to this study are from less than one barrel per day to about five barrels per day. Often the spill amounts constitute less than fifty parts per billion in the water column.

The most useful remote sensing methods related to chronic discharges are those that are operable in confined areas, where the sensor can be mounted on:

a) drilling platforms,

b) ships,

c) bridges, cranes, towers or wharves, or

d) buoys or floating structures.

The concept represents a major departure from "traditional" oil spill remote sensing. In general, airborne and satellite sensing systems monitor spills from a vertical angle, while sensors mounted on surface based platforms, monitor spills at a slant angle, thus altering the sensing geometry.

In terms of this study, certain limitations are imposed. Studies relating to oil spills on water and or in ice have always been directed at how the spill can be "seen" from satellites or aircraft. The concept of target and background signatures, which is the standard way to characterize a sensing response, are always discussed in terms of a target, a sensor and the medium between the two. These target/sensor interactions, as they appear in the literature, are usually in reference to studies carried out from aircraft or spacecraft platforms.

On first consideration, results of the studies outlined above may appear to be irrelevant to a study of ground-based remote sensing. However, two facts should be noted. First, remote sensing is a non-contact form of measurement, thus, in a target/sensor interaction, the composition and thickness of the intervening medium can change. Whether a target is measured over 1000 feet or 10 feet the basic underlying principles will not be altered, but changes will occur with respect to distance and geometry. Secondly, most remote sensing systems were introduced as laboratory prototypes, thus the distance between the target and sensor was probably only a few feet. Once a prototype proved successful, it was taken to the field and further testing was conducted. The basic principles remained constant, only the geometry of the view was changed.

In summary, this study will explain the basic methodology of remote sensing, make spatial adjustments to focus on a small area and volume of oil, and pollutant events, termed here as chronic oil discharge.

1.3 Acknowledgements

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Resource Engineering.

The information searches were conducted at both RESORS and OEIC. The resultant material was the developmental basis for a computer key word listing of NTIS and TULSA data bases.

F.G. Bercha and Associates staff professionals involved in this study included; Mr. E.J. McLaren, Mr. R.D. Worsfold, Ms. C. Hutton, Ms. S. Digby and Ms. S. Quennell.

SECTION 2

TARGET/SENSOR INTERACTION

Remote sensing is the non-contact measurement of surface phenomena. Target information can only be transmitted to a sensor by electromagnetic energy. Therefore, to understand the remote sensing process, it is necessary for the reader to have a functional knowledge of the electromagnetic spectrum and to be familiar with the actions and reactions that occur between electromagnetic energy and the medium through which it must pass, the target, and the sensing system.

Discussed within this section are; the petroleum pollutant target, the electromagnetic spectrum and characteristic spectral signatures of targets.

2.1 Target

Almost eighty percent of the world's oil spills are the result of vessel routine operational discharges at sea and regulations governing the control and clean-up of operational discharges have been established by International Convention. Unfortunately, careless operating procedures and maritime accidents do result in spills that must be controlled before damage occurs to the environment. These spills include catastrophic, accidental and chronic incidents. It is necessary to discuss the constituents of such spills prior to the commencement of the sensor evaluation procedure. The composition of various pollutants is important to the determination of sensors and systems most likely to assist in the detection and monitoring process.

2.1.1 Pollutants

Pollutants are mainly persistent petroleum products such as crude and fuel oil, but all types of petroleum, whether refined or unrefined, must be considered. The types of oil, and their properties, influence the type of spill that may occur and how it may be affected by wind, tides and currents.

Oil can be divided into crude oils and petroleum products. Crude oils are complex mixtures of hydrocarbons that range from simple, highly volatile substances to complex waxes and asphaltic compounds that cannot be distilled. They have varying molecular weights and there are three chemical structure groups: paraffine, naphthenic and aromatic. In addition, small quantities of oxygen, nitrogen, sulphur, vanadium, nickel, mineral salts and other elements, can occur in differing combinations.

The refining of crude oil results in petroleum products, and the chemical and physical characteristics of refined products depend on the source of crude used. Petroleum products can be subgrouped as follows: gasolines, kerosene, gas oils, fuel oils (light, medium and heavy); lubricating oils, etc.

For the most part, the physical and chemical characteristics of the various types of oil determine the spreading rate of the slick, its thickness and the emulsion types formed. These govern the behaviour of the spilled oil and ultimately the remote sensing method which can be used to detect, monitor and identify the incident. The major characteristics that have an effect on the methods of remote sensing are: chemical composition, specific gravity, surface tension, viscosity and pour point (Table 2.1).

Spreading, movement and weathering are the important effects of spilled oil in the environment.

Under ideal conditions, on a clean water surface, petroleum products will generally form a lens whose thickness will depend on oil type, air temperature, sea temperature, sea current and wind. Three general categorizations can be described as follows:

1) Large quantities - thick central region, surrounding thin film
2) Small quantities - thin uniform film
3) Very small quantities - very thin film quickly incorporated into the water column.

When calm seas predominate, the oil spreads in a circular fashion. As sea state increases, this circular pattern elongates in the direction of influencing winds and currents. Large amounts of oil in a roughened sea form viscous water-in-oil emulsions. Variances in the emulsion are dependent on wave motion, oil type and spill quantity. The emulsion

TABLE 2.1

CHARACTERISTICS OF OIL IN RELATION TO REMOTE SENSING APPLICATIONS

Characteristics of Oil	Effect Related to Remote Sensing
Chemical Composition	Certain elements or compounds may have an effect on the oil signature.
Specific Gravity	Most petroleum products have a specific gravity of less than 1.0, thus they float on water and can be detected with sensors. Those with a specific gravity greater than 1.0 float below the surface and will be difficult to detect.
Surface Tension	It is somewhat dependent on temperature and works with viscosity to affect the spreading rate. The lower the surface tension the greater the spreading rate.
Viscosity	The lower the viscosity the greater the rate of flow and hence spreading. It is also affected by temperature and spreading rate and will be a limiting factor on detection methods.
Pour Point	The temperature at which oil becomes a semi-solid or "plastic", and flow ceases.

causes a reduction in the spreading rate and large masses or clumps several centimeters thick can form.

The colour and appearance of a thin film may be used to estimate the thickness of an oil layer (Table 2.2). Under favourable light conditions, very thin layers of oil are barely visible, bright bands of colour appear, in medium layers, and dark colours predominate for layers approaching lens formation. Exceptions do exist when the spill is composed of some heavy residual fuel oils and certain crude types. These exceptions include petroleum products with a specific gravity greater than 1.0 and a pour point higher than the ambient water temperature. These products immediately form "tar" lumps.

In addition to the inherent movement caused by spreading, other factors such as current, wind and excessive surface debris will have an effect on the movement of oil. Wind greatly affects the movement of thin oil layers; tidal currents have the ability to move oil on the water's surface, but are mainly cyclic and do not have the same effect as the wind (speed and direction). When winds reach a speed that results in rough water, slicks begin to disperse and become difficult to see. Current also affects slicks, but the residual current information in a specific area is complex and difficult to obtain. Its effect on slick movement and dispersal is instantaneous and unpredictable.

As a general rule, an oil slick will move at a rate

TABLE 2.2

RELATION BETWEEN THE APPEARANCE, THICKNESS AND VOLUME OF FLOATING OIL

(Intera, 1983)

Oil Type	Appearance	Approx. Thickness	Approx. Volume (m^3/km^2)
Oil Sheen	silvery	0.0001mm	0.1
Oil Sheen	irridescent	0.0003mm	0.3
Crude & fuel oil	black/dark brown	0.1mm	100.0
Water-in-oil emulsions ("mousse")	brown/orange	1.0mm	1000.0

that approximates 30% of wind velocity. Coriolis forces have an effect on spill movement, however, this is relatively insignificant. In conditions which combine significant winds and water currents, resultant speed and direction must be considered. Another general rule states that winds in excess of 16 km/hr result in slick break-up (resultant sea state of 3).

In the marine environment, oil undergoes a natural degradation which changes its physical and chemical characteristics (i.e. viscosity, solubility, toxicity, etc.). This process is called "weathering". The major factors contributing to the weathering process of an oil slick are:

a) evaporation
b) dissolution
c) oxidation
d) emulsification, and
e) biodegradation.

During weathering, certain components are lost by natural processes, commencing when the spill occurs, and continuing as long as the oil is in the environment. Table 2.3 shows the processes and results.

Petroleum products may also occur in solution or suspension with other materials such as drilling mud or drilling debris. When it enters the water column the component parts of the solution or suspension can change the nature of the oil.

TABLE 2.3

WEATHERING OF OIL: PROCESSES AND RESULTS
(Fingas et al, 1979)

Process	Result	Resultant
Evaporation	- certain fractions lost to atmosphere - rate of evaporation decreases with time - rough seas, warm temperature and high winds increase evaporation - spreading enhances evaporation	- residues form - product to be sensed can change
Dissolution	- some components are lost to large surrounding water volume - long term processes - dissolution is low because of low solubility of oil - continues to act because oxidation and microbial degradation produces water soluble compounds	- changes chemical make-up of spill
Oxidation	- surface process that occurs more rapidly with thin films - slow process in general - changes components to water soluble products or emulsifiers - ultraviolet radiation from sunlight causes photo-oxidation	- dispersion increases
Emulsification	- one liquid becomes dispersed in another - two types - water-in-oil - oil-in-water - caused by wave action - oil-in-water normally separate out and reform slick (very unstable) - water-in-oil (very stable) called "chocolate mousse"	- type of emulsion results in different products to be sensed
Biodegradation	- dependent on temperature of oil and water mixture - oxidizing process	- changes components of slick

2.1.2 Sources

Various sources of oil pollution may be identified:

1) natural seepage
2) offshore oil exploration/production activities (mechanical failures and faulty operations)
3) marine casualties (stranding, collisions, etc.)
4) charging/discharging operations
5) cleaning procedures and ballast/deballast operations
6) terminal operations, (loading and unloading of cargo and bunkering)
7) transferring operations
8) land sources, and
9) atmospheric hydrocarbon fallout.

(Intergovernmental Maritime Consultative Organization, 1976).

In addition to this list, oil pollutants may be introduced during the discharge of drilling mud and cuttings from offshore exploration/development activities.

Within the context of this report, when the above sources are responsible for spill quantities of one to five barrels per day, or a measurable combination thereof, which results in the same cumulative effect over a one year time period, it will be considered a contributing target source of chronic discharge. Spills of this extent represent the target magnitude that must be sensed.

2.2 Electromagnetic Spectrum

The electromagnetic spectrum describes characteristics of the energy being sensed. No sensor is capable of detecting electromagnetic energy from all portions of the spectrum. Each sensor optimizes (is sensitive to) a distinct portion of the spectrum. Sensors are characterized or described according to the portion of the spectrum in which they operate.

The electromagnetic spectrum is a continuum of energy travelling at 3×10^8 m x $\sec^{-1}$. It can be expressed in terms of wavelength or frequency. For this report, wavelength and frequency will be interchanged as introduced by the cited authors. Figure 2.1 illustrates a standard representation of the electromagnetic spectrum. The more common bands are given names for convenience. The boundaries between these bands are gradational and distinctive regions of the spectrum are sensed by different types of sensors. A brief discussion of the most commonly utilized bands or regions follows.

2.2.1 Visible and Near Visible

The operational portion of this region extends from 0.3 micrometers (μm) to 1.5 micrometers (μm). Three regions (ultraviolet, visible and near infrared) are commonly grouped together due to the basic similarities in the sensors operated in these regions. Subdivisions are possible according to certain significant spectral properties.

The ultraviolet portion of the spectrum is very small,

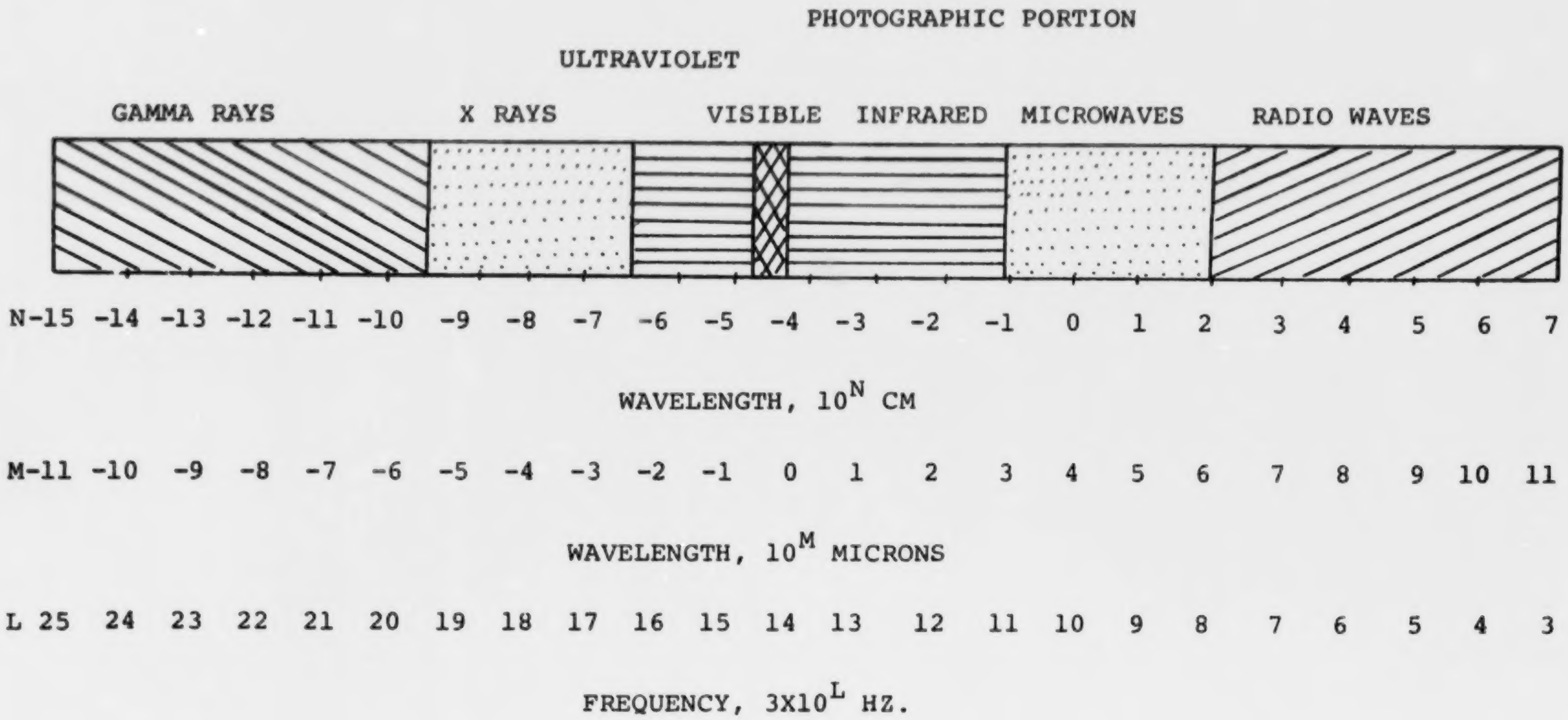

PHOTOGRAPHIC PORTION
ULTRAVIOLET
GAMMA RAYS
X RAYS
VISIBLE
INFRARED
MICROWAVES
RADIO WAVES
N-15 -14 -13 -12 -11 -10 -9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7
WAVELENGTH, 10N CM
M-11 -10 -9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10 11
WAVELENGTH, 10M MICRONS
L 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3
FREQUENCY, 3X10L HZ.

FIGURE 2.1 THE ELECTROMAGNETIC SPECTRUM

ranging from 0.3 to 0.4 μm and reflected energy is sensed. Absorption bands at less than 0.3 μm define the lower boundary of the ultraviolet region.

The visible region extends from 0.4 to 0.70 μm and reflected energy is again sensed by the remote sensing devices. The major difference between the visible region and the ultraviolet region corresponds to the sensitivity of the human eye.

Just beyond the visible, extending to about 1.2 μm, is the near infrared region. Energy in this region cannot be seen by the human eye but, like the ultraviolet region, is mainly reflected energy that can be recorded by cameras and similar sensors.

2.2.2 Middle and Far Infrared (Thermal IR)

Beyond 1.2 μm the effects of reflected energy dissipate rapidly and cease to be a factor in sensing at approximately 3.0 μm. Beginning at about 3.0 μm the thermal energy, due to molecular motion, becomes the primary source of detectable energy. The middle and far portion of the infrared region extends from 1.2 μm to 300 μm. The major operating portions of the thermal infrared band are from 3.0 μm to 5.0 μm (middle infrared) and from 8.0 μm to 14.0 μm (far infrared).

In the remaining and major portion of the infrared band, energy is absorbed by atmospheric constituents like water, oxygen, ozone, etc. The areas where energy is permitted to pass are termed "atmospheric windows" and were defined above.

2.2.3 Microwave/Radar

The microwave portion of the electromagnetic spectrum is considered to extend from approximately 1 millimetre to 1 metre in wavelength (300 GHz to 300 MHz in frequency). Microwave energy can penetrate cloud cover and some rain, and its passage is almost independent of moisture at the lower microwave frequencies. As a result, microwave systems can provide timely information, under both day and night conditions, when other systems become inoperable due to cloud, fog or darkness. Microwave responses are functions of frequency (or wavelength), polarization, and look direction. Responses are dependent on the electrical and physical properties of the target, such as surface roughness and subsurface structure. Skin depth, or depth of penetration of electromagnetic energy, within a material, is directly proportional to wavelength. The long wavelength microwave responses are influenced more by subsurface properties than are short-wave visible and IR radiation. Also, as the surface roughness is defined relative to wavelength, a surface which appears rough to visible and IR wavelengths would appear smooth to microwave radiation.

2.2.4 Other Sensing Regions

There are other regions of the electromagnetic spectrum that can be sensed with remote measuring systems. These are not as commonly used as those discussed above, but nevertheless may have a role in the remote sensing of chronic oil discharges. At wavelengths very much shorter than the ultraviolet, less than 0.003 μm, is the gamma ray region. Measurements in this region are dependent on the nuclear properties of the materials. Other spectral regions of potential use are the very long wavelengths, beyond the microwave region, in the radio or broadcast bands. In this region sound waves or acoustics may have some importance in the detection of chronic oil discharges.

2.2.5 Sensors General

Although sensors will be discussed in detail in Section 3, a brief word is included at this point to assist in the discussion of target/sensor interaction.

Sensors can be grouped into two categories: active and passive. Active sensors provide their own source of energy (or illumination), causing reflection, or stimulating emission. This involves a two-directional energy path, from the sensor to the target and return. Therefore, the signal passes through the intervening sensing medium twice, which can result in certain signal attenuations. The active sensor stimulates energy in a selected electromagnetic spectral region. Passive sensors measure or detect the naturally reflected or emitted electromagnetic energy radiated from a target. A target emits energy over the total spectrum, but the passive sensor records only over a selected spectral range. Passive sensing involves measurement over a one direction energy path.

Sensors can be categorized as to the method by which data is recorded - imaging or non-imaging. An imaging sensor provides a data output in a two-dimensional pictorial form (i.e. photograph, video). A non-imaging sensor provides an output in a non-pictorial form (i.e. numerical, graph, line trace).

A sensor must be mounted on a platform such as a satellite, an aircraft, or be ground-based. Of major concern to this study are ground-based platforms including moving and stationary vessels, buoys, floating towers; confined structures such as bridges, wharves, towers, etc. Through the years many reliable sensor suites or packages have been developed for use with a variety of platforms.

Depending on the user's information requirement, target/sensor interaction studies have defined combinations of sensors and platforms that can be used or developed to meet the requirement. It should be noted that the normal sequence of development begins with a laboratory prototype, progressing through aircraft and possibly spacecraft utilizations. Thus, for this study, logic demands a reversal of this process, assessing currently used and available sensors and re-applying them to meet surface sensing requirements.

2.3 Interaction Process

The ability to remotely measure an oil pollutant depends on the interaction between the electromagnetic energy radiating from the target and the ability of the sensor to make a measurement. Due to material property differences between oil and background materials (water and ice) a measurable target contrast exists. The difference in contrast is due to the reflectivity, emissivity, luminescence, form, texture, measurement wavelength or frequency, period of observation, polarization and observation angle dependence. Variations in the sensors registration capabilities and influence presented by the transmission medium (air or water) will alter the appearance of the signal. If this appearance is standardized through multiple observations and is constant with, or over, a range of values, it can be termed a "Characteristic Signature". This infers that under a given set of conditions measurements will always be the same.

A major problem in the determination of a characteristic signature are influencing parameters not coupled, or non-associated, with the oil slick. Examples of these parameters include, atmospheric conditions, time of observation, oceanographic conditions and the content of dissolved and suspended material in the water column. Both target backgrounds and the transmission medium can be affected by these parameters.

2.3.1 Ultraviolet Signatures

The ultraviolet spectral region is often sub-divided into the far ultraviolet (0.1 to 0.2 μm), the middle ultraviolet (0.2 to 0.3 μm) and the near ultraviolet (0.3 to 0.4 μm). Previous studies have shown that detection of oil is impossible below 0.29 μm and beyond the far ultraviolet due to severe atmospheric attenuation. Oil has a significantly higher reflectance than water in the 0.3 to 0.4 μm region. Sensors operating in this region have a good potential ability to detect oil pollutants. From a photographic viewpoint, the characteristic yellow, brown and brownish-black colours are related to the strong ultraviolet absorption ability of oil. This absorption extends into the visible region (Catoe and McLean, 1979).

2.3.2 Visible Signatures

This spectral region corresponds to the sensitivity of the human eye. The basic mechanism for oil detection in this region is again the reflectance contrasts between oil and water. Reflectance consists of two components, the specular and the diffuse. The specular component of oil is always greater than that of the water, while, the diffuse component of oil is usually less than the water's. The maximum contrast between oil and water occurs in two distinctive regions, less than 0.4 μm (the ultraviolet/blue region) and the greater than 0.6 μm (the red region). The minimum contrast occurs between 0.45 and 0.50 μm (Catoe and McLean, 1979).

Because reflectance is a guiding parameter and is totally dependent upon the sun as the illumination source, sky conditions will greatly influence the oil/water contrast. Studies have shown that the best contrast is evident when the sky is overcast.

2.3.3 Near Infrared Signatures

Catoe and McLean (1979) noted that the radiance from an oil slick, in the near infrared region, is from 20% to 100% greater than the radiance of the background water. Therefore, this region is very useful for the daytime detection of oil slicks. The same authors also report that there is sufficient diffuse illumination provided by starlight and airglow to create approximately 50% greater radiance from oil than from water. This statement was not supported by a specific reference, and it is concluded that some form of low light device was used to record the signature.

2.3.4 Mid- and Far Infrared

The major signature variables in these regions are the differences in emissivity between oil and water; surface temperatures; thermal conductivity; thermal diffusivity; solar heating; evaporation rates; etc. For example, in the spectral region 8.5 to 12.5 μm, the emissivity of water is .988 and the emissivity of oil is between .94 and .97. Therefore, oil will have a radiant temperature lower than the radiant temperature of the water. Oil will appear cooler, and depending on its thickness, it can appear as much as 3°K cooler than water.

According to Neville et al (1979), the presence of an oil layer on the surface of the sea can have one, or a combination of effects, on the physical temperature of the surface.

- "Optically thick oil can absorb sufficient solar irradiation to heat it above the water temperature."
- "Oil near the source of the spill may retain the source temperature which could be different from that of the water."
- "Volatile components from freshly spilled oil may provide cooling by increased evaporation."
- "Less volatile oils may impede evaporation of the water, thereby producing a warming effect."
- "An oil film can impede the flow of heat at the water surface, resulting in an increased or decreased surface temperature depending on whether the air temperature is above or below the water temperature."

2.3.5 Passive Microwave Signatures

The major benefit to sensing in this region is that passive microwave systems have all-weather day and night capabilities. Due to the passive nature of the measuring system, the natural emissive radiation of the oil and background are used to detect oil. For the passive microwave region (0.1 cm to 30 cm) the emissivity of oil is significantly higher than that of water. Microwave detection capability is well documented (Edgerton et al, 1975; Meeks et al, 1971; and Hollinger et al, 1973). Catoe and McLean (1979) state that the brightness temperature of oil is inversely proportional to the sensor wavelength. Stated in other words, the ability to detect an oil slick improves as the wavelength becomes shorter. However,it is limited as the shorter wavelengths begin to approach the capillary wavelengths.

Oil has a dampening effect on the sea state. An oil film on a moderate-to-rough ocean can result in a calming effect which can manifest itself as a lower surface temperature. Thick films of oil (greater than 0.1 mm) emit more microwave energy than clean water due to their lower dielectric properties. There is a general concensus by all authors that oil on water has a unique microwave signature. Catoe (1973) provides the following conclusions:

1) the ability to detect an oil film using microwave radiometry is inversely proportional to the sensor wavelength,
2) the minimum detectable oil film thickness using a dual-polarized 0.81 cm radiometer appears to be in the range of 10 to 20 μm,
3) the roughness of the ocean surface affects the microwave signature, and
4) a microwave radiometer used for oil pollution detection must operate at wavelengths of 8 mm or less.

O'Neil (1981) states that of all the state-of-the-art sensors, microwave radiometers give the most direct measurement of oil film thickness.

2.3.6 Radar Signatures

The ability to detect oil on water using airborne imaging radars is possible due to the dampening effect of oil slicks on the ocean waves. The short capillary waves that are superimposed on longer ocean waves act as scattering sources. Oil dampens these capillary waves, reducing the number of scattering sources. In surrounding areas, where oil is not present, the number of scattering sources due to the capillary waves remains high. The resulting radar image depicts the oil dampened area as a black region of little or no return and the undampened regions as grainy grey-white tones.

According to Catoe and McLean (1979) vertical radar polarizations gave the best contrasts for oil on water, thus the best potential, while horizontal and cross-polarizations resulted in very little oil/water contrast. This effect is due not to oil characteristics, but the characteristics of the slightly rough surfaces viewed at shallow depression angles.

2.3.7 Other Signatures and Considerations

When attempting to locate oil in a marine environment it is essential that the discharge is clearly discriminated from its background. The capabilities of a sensor will vary with the type of discharge, amount of discharge, background characteristics and sensor type. From the literature it can be seen that there is basically enough information available to identify or characterize oil in each of the major remote sensing spectral regions. There are usually some overriding considerations, such as the signature's validity, for certain oil types. Immediately evident is the lack of available data with respect to oil mixed with drilling debris and muds. Hence, characteristic signatures for these cases cannot presently be determined. Evidence from the literature review has shown all characteristic signatures of oil have been determined from studies involving large oil spills. No information exists for signatures from smaller quantities (i.e. 1 to 5 barrels) that would be classified as chronic discharges as previously defined. Studies concerning smaller spill quantities, that will not form a slick or sheen or any type, but instead enter the water column, are grossly deficient in existing literature.

Additional factors that will influence oil detection by altering the contrast between oil and water, is the nature of the background. These factors can mainly be grouped as atmospheric, oceanographic and ice. Oceanographic effects are wavelengths, currents, wind direction, salinity, sediment load, presence of other pollutants, and biomass. These can all affect the background signature as well as the target signature. Atmospheric events do not have as great an impact, but rain squalls or wind shears can affect some sensor operations.

The presence of ice can have a profound effect. Ice signatures will vary with respect to ice type, concentration, size, surface roughness and motion. Ice will effectively hide the presence of oil by trapping it beneath the ice.

SECTION 3

SENSOR SYSTEMS

There is no sensing device that will operate over the entire electromagnetic spectrum. It should also be apparent that no one specific sensor is capable of meeting the information needs of various types of spilled oil on a diversity of backgrounds, and for a variety of surface and atmospheric conditions. Discussed in this section of the report are detailed descriptions of available sensors, mainly used in aircraft, that have the potential utilization in a surface sensing mode. Each generic type of sensor will be described, their operating capabilities within specific spectral ranges discussed, and where available, example systems will be discussed and/or limitations foreseen in their use for chronic oil discharge will be outlined.

3.1 Visible/Near Visible/Infrared Sensors

The sensors discussed in this section include some of the oldest and newest sensor systems available. They are passive and active; normally requiring the absence of cloud, moisture or atmospheric particulates in the target/sensor path. Systems are very diverse, and are grouped into categories based on the type, since many are capable of sensing in more than one of the spectral regions.

3.1.1 Photographic Sensors

Photographic sensors are the oldest of all the sensor systems and are the most thoroughly tested and utilized. They are passive, and are among the least expensive of sensing systems. The human eye responds to essentially the same part of the electromagnetic spectrum, thereby easing the interpretation of the resultant photographs. Photographic systems record ultraviolet, visible and/or near infrared radiation. Figure 2.1 shows the photographic region of the electromagnetic spectrum and its relation to the broader spectrum. Photographic film can record reflected solar radiation in the near infrared region but not the thermal region.

Film emulsion is a suspension of silver halide crystals in a protective colloid (usually gelatin). The initial action on the film is the formation of the latent image by exposure to light. Light decomposes the silver halide into metallic silver and halogens. After exposure the film is developed, a process which selectively reduces more silver halide crystals near the original metallic particles, into large deposits of metallic silver.

The transfer of information from the original energy distribution to the photographic image is described by the characteristic curve (Figure 3.1) which illustrates the relationship between film density and exposure. Two im-

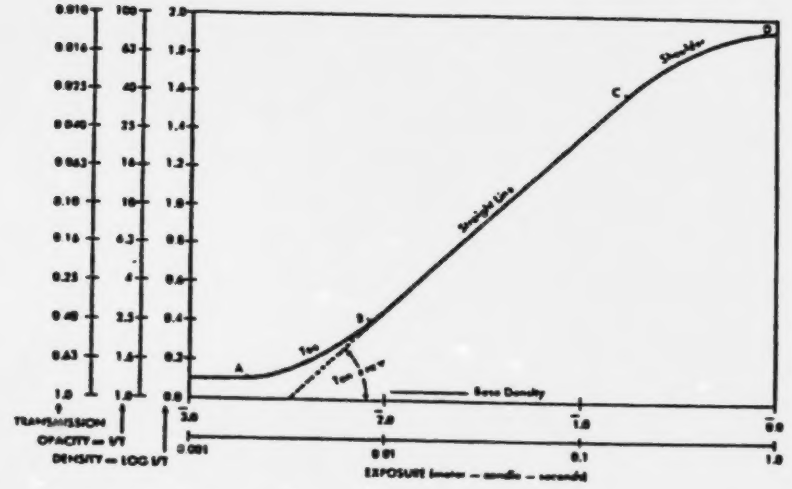


FIGURE 3.1 A CHARACTERISTIC CURVE OF OPTICAL FILM DENSITY VERSUS THE LOGARITHM OF THE ESPOSURE (Kodak, 1972)

portant parameters of the film recording process are the film's gamma and its dynamic range. The gamma of a film is the slope of the straight line portion of the characteristic curve and is a measure of the film's contrast. The film gamma determines the density interval into which an intensity differential will be mapped. The dynamic range is the length of the straight line portion of the characteristic curve and is a measure of the maximum intensity interval that can be recorded within the linear range of the film operation. The dynamic range is usually limited to about 20 dB.

The resolution of a film may be described by the modulation transfer function in terms of cycles per millimeter. This term refers to the number of alternate black and white lines which can be identified on a film. On film, the spatial resolution is inversely proportional to the grain size. The grain size and the radiometric resolution is directly proportional to the film sensitivity. As with any recording medium there are several distortions involved, which in the case of film, are basically of two types: exposure effects and adjacency effects. Some characteristics of common black and white aerial films are shown in Table 3.1.

A colour film is composed of three emulsions which are sensitive to light of different wavelengths. Two colour systems are in common use. The additive system colours are red, blue and green while the subtractive systems colours are cyan, magenta and yellow. These two systems are related in

TABLE 3.1

CHARACTERISTICS OF AERIAL PHOTOGRAPHIC FILMS

(American Society of Photogrammetry, 1975)

Film Name	Film Number	Nominal Base Thickness (μm)	Aerial Film Speed (AFS)	Aerial Exposure Index (AEI)	Developer or processes	Resolving Power, lines/mm target-object contrast		Diffuse RMS granularity[f]
						1000:1	1.6:1	
Plus-X Aerographic	2402	100	200	80	D-19	100	50	19
Tri-X Aerographic	2403	100	650[c]	250	D-19	80	20	33
Double-X Aerographic	2405	100	320[c]	125	DK-50	80	40	26
Panatomic-X Aerial	3400	60	64	20	D-19	160	63	16
Plus-X Aerial	3401	60	200	64	D-19	100	40	30
High-Definition Aerial	3414	60	8	2.5	D-19	630	250	9
	1414	40	8	2.5	D-19	630	250	9
Infrared Aerographic[a]	2424	100	200	100	D-19	80	32	33
Multispectral Infrared Aerial[a]	SO-289	100	100			200	80	12
Aerochrome Infrared[b]	2443	100	40	10	EA-5	63	32	17
	3443	60	40	10	EA-5	63	32	17
High Definition Aerochrome Infrared[b]	SO-127	100	6[c]		EA-5	160	50	9
	SO-131	60	6[c]		EA-5	160	50	9
	SO-130	40	6[c]		EA-5	160	50	9
Aerocolor Negative	2445	100	100[c]	32[e]	Aero-Neg. color proc.	80	40	13
Ektachrome MS Aerographic	2448	100	32[c]	6[e]	EA-4	80	40	12
Aerial Color	SO-242	60	6	2	ME-4 (modified)	200	100	11
	SO-255	40	6	2		200	100	11
Ektachrome EF Aerographic	SO-397	100	64[c]	12	EA-4	63	32	13
	SO-154	60	64[c]	12	EA-4	63	32	13
Water Penetration Aerial Color	SO-224	100	40[c]		EA-5	125	50	24
Anscochrome	D/200	100	90[d]	30	AR-1C	100	50	25
Anscochrome	D/500	100	230[d]	75	AR-1C	80	40	45

a very specific way. The subtractive primaries each consist of the wavelengths in two additive primaries. For example, cyan = green + blue.

Colour films may utilize either a direct positive process or a negative-positive process. Both are in common use, but the negative-positive type provides better images and greater versatility. IR colour film is basically the same as normal colour film, except for a difference in the sensitivity of one of the three layers and the dye colours used, which results in a false colour presentation. In remote sensing, the problems of colour balance and repeatability are significant since quantitative information may be needed.

Although many different camera systems are in use today for remote sensing, all operate on the same basic principles. An image is recorded through a lens, and by changing the focal length of the lens, the relative size of the image can be changed. Aperture control is provided to control the amount of incident light, and variable shutter speeds are available to control the exposure more precisely. Elaborate film transport systems have been developed which advance the film automatically between exposures. The camera's case may be designed for special environments and may be air- or water-tight as well as light-tight.

The ability to interchange lenses and shutters on a camera system greatly extends its capability. An aerial camera system can be controlled to produce images of varying scale by changing either the focal length of the lens or the altitude of the aircraft. As the range over which either may be varied is limited, it is important that alternatives be available.

The amount by which the film is exposed is determined by the product of the light intensity passing through the lens and the amount of time the shutter is open. The primary constraints on these two parameters are: platform speed, film speed, spectral bandwidth, maximum lens aperture and target range.

Even the most perfect lenses have several distortions. Some lenses tend to reduce these distortions, but compromises have to be made; for example, exact geometric fidelity may be gained at the expense of resolving power. Basic types of shutters used on aerial cameras are focal plane and leaf or blade systems. The focal plane shutter can cause serious distortions of the image due to aircraft motion.

Several different camera formats are in common use in remote sensing. Each format has features and capabilities which make it suitable for specific remote sensing applications such as reconnaissance, mapping, or the determination of target spectral signatures.

Aerial cameras use a variety of film sizes ranging from 35 millimetres to 23 centimetres in width. The film size required for a specific application is determined by the scale required, ground coverage required, type of aircraft available, and several other factors concerning the film, lens, and illumination. The ground area covered on a single frame is determined by film size, lens focal length and altitude. The distance on the ground is given appropriately by h tan θ, where h is the aircraft altitude and θ is the angular field of view of the lens-film format combination. Image motion must be considered when undertaking any aerial photography as it causes directional smearing of the image resulting in distortion and an increased resolution cell size.

There are three basic types of conventional aerial photographic cameras

1) Framing cameras and metric framing cameras
2) Strip cameras
3) Panoramic cameras.

There are two types of framing cameras; metric (mapping) and reconnaissance. The most distinctive feature of a metric camera is its low degree of distortion in the lens which results in a reduction of resolving power. Metric camera lenses normally have a field of view of either 74 or 104 degrees with a negative size of 9 inches x 9 inches (23 centimetres x 23 centimetres) and an aperture of between f/4 and f/6.3 (Table 3.2). There are fiducial marks which are exposed simultaneously with the ground scene, and are used for locating the principal points. In addition, exten-

TABLE 3.2 EXAMPLES OF SOME COMMERCIALLY AVAILABLE MAPPING-FRAME AERIAL CAMERAS
(Types and Characteristics)

CAMERA DESCRIPTION	PRIMARY USE	FILM INFORMATION				CYCLE RATE	OPTICS			RESOLUTION (L/mm)	SHUTTER		WEIGHT kg	MOUNTS	DATA ANNOTATION	INTER-VALOMETER	EXPOSURE CONTROL	REMARKS
		FORMAT (cm)	LENGTH (m)	FRAMES/ROLL	MAGAZINE		FOCAL LENGTH (mm)	F NUMBER RANGE	ANGULAR COVERAGE (DEGREES)		SPEED	TYPE						
RC-10 Wild Heerbrugg	General mapping	23x23	150	500	Cassettes	1.5	150 or 90	5.6 to 22	74x74 104x104	55	1/100 to 1/1000	rotary	78	PAV-10 or NA	Clock altitude counter	Yes	Manual, remote	No reseau
MRB 15/2323 Jena	Medium/high Altitude mapping	23x23	120 to 150	450	Interchangeable W/MRB 9	2.0	150	4.5 to 8.0	74x74	NA	1/100 to 1/1000	rotating disc	63	Universal MRB-A	Clock altitude & grey scale	Yes	Optional	Peripheral reseau
MRB 11 5/1818 Jena	Medium/high Altitude mapping	18x18	120 to 150	540 (max)	NA	NA	115	4.0 to 8.0	90x90	NA	1/100 to 1/1000	rotating disc	37	Universal MRB-A	Clock altitude & grey scale	Yes	Optional	Peripheral reseau
Model VI Galileo Corp. of America	Mapping	23x23	110	NA	Interchangeable	5.0	150	5.6 to 11.0	74x74	NA	1/25 to 1/300	NA	38	special	NA	Yes	NA	Reseau optional
RMK A 8.5/23 Carl Zeiss	Aerial survey	23x23	120	470	NA	2.0 to 180	85	4.0 to 8.0	107x107	NA	1/50 to 1/500	Aerotop rotating disc	60	ASV shock & vibration absorbing	auxiliary	IRU	Auto W/EMI 2	No reseau
RMK A 15/23 Carl Zeiss	Aerial survey	23x23	120	470	NA	2.0 to 180	150	5.6 to 11.0	74x74	51	1/100 to 1/1000	Aerotop rotating disc	57	ASV shock & vibration absorbing	auxiliary	IRU	Auto	Optional reseau with pleogon AR lens
RMK A 60/23 Carl Zeiss	Aerial survey	23x23	120	470	NA	2.0 to 180	610	6.3 to 12.5	23x23	NA	1/100 to 1/1000	Aerotop rotating disc	54	ASI, III shock & vibration absorbing	auxiliary	IRU	Auto W/EMI 2	No reseau
T-11 & T-11D Fairchild	Medium/high Altitude mapping	23x23	120	450	Integral	3.0	150	6.3 to 11.0	74x74	20	1/10 to 1/500	Intra lens rapidyne	39 (with film)	A-8-11-25-28-32 ART-21-25	counter, clock, card, etc.	Yes	Manual	No reseau
KC-6A Fairchild	Medium/high Altitude mapping	23x23	120/240	470/940	Integral	2.0	150	5.0 to 11.2	74x74	45	1/50 to 1/800	Intra lens rapidyne	66 (with film)	LC-7A	CRT, counter, fixed data	Yes	Auto (AEI 20-2000)	Platen reseau
F-639 Fairchild	Medium/high Altitude mapping	23x23	215	770	Integral	2.0 (max)	150	5.6	74x74	56	1/25 to 1/900	Intra lens rapidyne	45 (with film)	Hard, with insulators	counter, clock, card, etc.	Yes	Auto (AEI 6, 20, 64)	Platen reseau

sive flight and camera data are recorded on each exposed frame.

Reconnaissance cameras have a higher resolving power than metric cameras but with a corresponding increase in distortion (Table 3.3). In contrast to metric cameras, reconnaissance cameras are available in a wide variety of configurations making these systems difficult to characterize briefly. These cameras are designed to operate with high resolving power and wide apertures without any distortion correction. They normally have narrow fields of view, generally 10 to 70 degrees and focal lengths of a few millimetres up to 450 millimetres. They normally operate with focal plane shutters, and fiducial marks are incorporated into the optics. The resolving power of these cameras varies widely and they provide high velocity-to-height ratios for their use in high performance aircraft.

The strip camera was developed in the 1930's and since then there have been very few new developments (Table 3.4). The continuous strip camera works on the principle of moving the film behind a slit in the focal plane of the camera at exactly the same velocity that the image is moving past the slit. These cameras have been used in large photoreconnaissance systems.

For a given width of coverage, a smaller field of view angle is needed than for a frame camera (i.e. the area covered with a 74 degree strip camera is the same as with a 90 degree frame camera). Resolving power is higher but

TABLE 3.3 EXAMPLES OF SOME COMMERCIALLY AVAILABLE RECONNAISSANCE CAMERAS

(Types and Characteristics)

CAMERA DESCRIPTION	PRIMARY USE	FILM INFORMATION					CYCLE RATE (fps)	OPTICS			RESOLUTION (L/mm) (TC 1000:1)	SHUTTER		REMARKS
		FORMAT (in)	WIDTH (in)	LENGTH (ft)	FRAMES (per roll)	MAGAZINES		F/L (in)	MAX APT	ANGULAR COVERAGE		SPEED	TYPE	
CA-3-2 (Fairchild)	Day Recon	9x9	9.5	390 390 200 390	490 490 250 490	LA-12 (FMC) LA-129 (FMC) A-5A (MA-5) A-90 (MA-4)	0.8 0.8 0.8 0.8	6 12 24	6.3 5.0 6.0	73°44' 41°06' 21°14'	25 plus-x 15 sup-xx 15 sup-xx	1/90-1/400 1/75-1/225 1/90-1/150	BTL	Manual exposure control
CA-13 (Fairchild) (Gordon)	High altitude Day Recon	9x18	9.5	600 75 390	325 45 245	A-25 (FMC) A-7 A-80 (MA-8)	1.0 0.66 0.66	12 24 36	6.3 6.0 8.0	41°06'x73°44' 21°14'x41°06' 14°14'x21°14'	20 plus-x 26 plus-x 30 sup-xx	1/90-1/250 1/90-1/150 1/90-1/150	BTL	Manual exposure control
CA-17 (Fairchild) (General Electric)	Med/High alt. Night Recon	9x9	9.5	200 390 390	250 490 490	A-5A A-9B A-14, A-18, & A-28 (All FMC)	0.4 0.4 0.4	12 24	2.5 4.0	41°06' 21°14'	16 plus-x 16 plus-x	1/25-1/100 1/25-1/100	BTL	Manual exposure control
CAX-12 (Fairchild)	Low altitude Day Recon	2.25x2.25	2.76 (perf)	100 100	400 400	LA-30 LA-30	0.33-10.0 0.33-5.0	1.5 1.5 3 6 12	6.3 4.5 3.5 3.5 4.0	73°44' 73°44' 41°06' 21°14' 10°42'	39 plus-x 53 plus-x 40 plus-x 44 plus-x 40 plus-x	1/90-1/700 1/90-1/700 1/50-1/700 1/50-1/400 1/50-1/200	BTL	Manual exposure control
K-22A (Hycon) (Hoover modification)	Day Recon Charting	9x9 8x10	9.5	200 390 sheet film:	250 490	A-5 & A-5A A-9B B-1	0.5 0.5 Manual - -	6 12 24 40 40 40	6.3 5.0 6.0 5.0 5.6 8.0	73°44' 41°06' 21°14' 12°50' 12°50' 12°50'	25 plus-x 15 sup-xx 15 sup-xx	1/150-1/800 1/150-1/800 1/150-1/800 1/150-1/800 1/150-1/800 1/150-1/800	Focal Plane	Manual exposure control
KA-30A (CAI)	Day/Night Recon	4.5x4.5	5	100	250	LA-135A	AC -6 Night -2 FMC-Pulse -2 Pulse-1	6	2.8	41°06'	30 plus-x	1/50-1/800	BTL	Manual exposure control
KA-45A (CAI)	Day/Night Recon	4.5x4.5	5	250 100	600 250	LA-141A LA-135A	AC -6 Night -2 Night X -6 FMC Pulse -2 Pulse -1	6	2.8	41°06'	44 plus-x 55 pan-x	1/60-1/3000	Focal Plane	Manual exposure control
KA-80A (CAI)	Low altitude Day/Night Recon	4.5x4.5	5	250 100	600 250	LA-141A Cassette	AC -6 FMC Pulse -2 Pulse -1	1.75	5.6	104°20'	40 pan-x	1/60-1/3000	Focal Plane	Binary data annotation system AEC
KC-3 (Aeroflex)	Day mapping	9x9	9.5	390	450	KC-3	0.40	3.5	5.6	104°50'	24 sup-xx	1/100-1/800	BTL	
KF-8 (Mitchell)	High speed	0.631x0.868	1.38	1000	16.000	GC-276	24-128	2 4 6 10	2.3 2.3 2.3 4.5	18°18'x25°00' 9°06'x17°36' 6°06'x8°24' 3°37'x4°50'	NA	1/17-1/3072	170° Rotary	Remote controlled diaphram Motion Picture
KS-72C-1 (Hycon)	Day/Night Recon	4.5x4.5	5	500 250	1200 600	LA-283A LA-284A (IFP)	Day -6 Night -3	3 d/n 6 d/n 12 day 18 day	4.5 2.8 4.0 4.0	73°44' 41°06' 21°14' 14°14'	40 plus-x 38 plus-x 53 pan-x 60 plus-x 65 plus-x	1/100-1/4000 (Day) 1/25-1/100 (Night)	Focal Plane (day) BTL (night)	Binary data annotation system AEC
KS-87A (CAI)	Day/Night Recon	4.5x4.5	5	500	1200	LA-354B	FMC Pulse -6 Pulse -6	3 6 12 18	4.5 2.8 4.0 4.0	73°44' 41°06' 21°14' 14°14'	80 pan-x 90 pan-x 90 pan-x 58 plus-x 50 pan-x	1/60-1/3000 (Day) 1/25-1/100 (Night)	Focal Plane (Day) BTL (night)	Binary data annotation system AEC

TABLE 3.4 EXAMPLES OF SOME COMMERCIALLY AVAILABLE STRIP CAMERAS

(Type and Characteristics)

CAMERA DESCRIPTION	PRIMARY USE	FILM INFORMATION					CYCLE RATE (FPS)	OPTICS			RESOLUTION (L/mm) (TC 1000:1	SHUTTER SPEED	REMARKS
		FORMAT (IN)	WIDTH (IN)	LENGTH (FT)	FRAMES (PER ROLL)	MAGAZINE		F/L (IN)	MAX APT.	ANGULAR COVERAGE			
CAS-2a (CAI)	Day Recon	4.5 x strip (two stereo)	9.5	205 390	strip strip	cassette	0.5-25 continuous	4(2) 7(2) 12(2) 20(2)	3.5 2.5 5.0 5.6	59°30' 35°38' 21°14' 12°50'	NA	Variable slit width & film velocity	Manual exposure control
KA-18A (CAI)	Low alt, High speed, Day Recon	4.5 x strip (two stereo) 9 x strip	9.5	250 500	strip strip	cassette	strip	3(2) 6 6(2)	6.3 6.3 2.5	41°06' 73°44' 73°44'	28 sup XX 17 sup XX	Variable slit width & film velocity	AEC
S-11 (Bill Jack)	Low alt, Day Recon	4.5 x strip (two stereo) 9 x strip	9.5	200	strip	S-11	0.15-40.0 continuous	3.5(2) 6 7(2) 20	6.8 6.3 2.5 5.6	68°50' 73°44' 35°38' 12°50'	NA	Variable slit width & film velocity	AEC

distortion is also higher when compared with metric cameras. The focal plane slit is contoured to compensate for the lack of uniformity in exposure across the film width. Therefore, exposure is increased at the edge of the field to match the centre. On the metric camera, the exposure at the centre is reduced to match the exposure at the edge by the use of an anti-vignetting filter.

There are two basic types of panoramic cameras, rotating prism and scanning lens (Table 3.5). In the first type, a prism rotates in front of a stationary lens at half the rate that the film moves past a stationary slit. In the second type, the lens and slit rotate while the film remains stationary during exposure. The scanning lens cameras provide direct scanning and the lens-slit combination (slit-scan or optical-bar panoramic). The film surface is cylindrical in these cameras and the width of the film is parallel to the axis of the cylinder. The basic geometry of operation in a panoramic camera is shown in Figure 3.2 and the distortion that will occur in the panoramic image is shown in Figure 3.3. Several methods have been developed to correct these distortions in the printing process.

Panoramic cameras have small instantaneous fields of view because the image passes through a narrow slit immediately in front of the film. Therefore, their operational resolving power is typically high. The slit equals the film width while slit width is usually variable to control the exposure time. These cameras usually have a large angular

TABLE 3.5 EXAMPLES OF SOME COMMERCIALLY AVAILABLE PANORAMIC CAMERAS

(Types and Characteristics)

CAMERA DESCRIPTION	PRIMARY USE	FILM INFORMATION					CYCLE RATE (fps)	OPTICS			RESOLUTION (L/mm) (TC 1000:1)	SHUTTER		REMARKS
		FORMAT (in)	WIDTH (in)	LENGTH (ft)	FRAMES/ ROLL	MAGAZINE		F/L	MAX APERTURE	ANGULAR COVERAGE		SPEED	TYPE	
KA-56A KA-56B (Fairchild)	Low altitude Day Recon	4.5 x 9.4	5 (perf)	1000 500	1200 600	Magazine Cassette (IFP)	1-6	3	4.5	73°44' x 180°00'	33 plus-x	1/90-1/5000	Focal Plane variable slit	AEC-ELAAC Binary data annotation system
KA-57A (Perkin Elmer)	Low altitude Day Recon	2.25 x 8.247	2.76 (perf)	3000 (tb)	3600	Cassette	5	3	2.8 (twin lens & twin prism)	41°06' x 180°00'	100 pan-x	1/75-1/800	Focal Plane variable slit	AEC- Part of KS-68A Binary data annotation system
KA-58A (Perkin Elmer)	High altitude Day Recon	4.5 x 44.1	5	2500	535	Magazine	1.13	18	4.0 (twin lens & twin prism)	14°14' x 180°00'	125 EK 4404	1/75-1/800	Focal Plane variable slit	Binary data annotation system - Part of KS-69A
KA-59A (Fairchild)	High altitude Day Recon	4.5 x 30.0	5 (perf)	3500 (tb)	1600	SA-59A	.017-1.0	12	3.2	21°14' x 180°00'	45 plus-x	1/100-1/5000	Focal Plane variable slit	AEC
KA-71A (Fairchild)	Low altitude Day Recon	2.25 x 9.4	2.76 (perf)	250	300	SA-71	4-8	3	2.8	40°00' x 180°00'	40 plus-x	1/400-1/8000	Focal Plane variable slit	25 produced SRA version of KA-60A with AEC & FMC omitted
KA-73( ) (Perkin Elmer)	Low altitude Day Recon	2.25 x 8.25	2.76 (perf)	1500	1800	Cassette	0.5-5.0	3	2.8 (twin lens & twin prism)	41°06' x 180°00'	70 EK 3400	1/75-1/800	Focal Plane variable slit	AEC Binary data annotation system
KB-78( ) (Fairchild)	Low/medium altitude Day Recon	4.5 x 9.4	5 (perf)	1000	1200	Integral	AC-1-12 Pulse-0.5	3	2.8	81°00' x 180°00'	30 pan-x	1/40-1/12000	Focal Plane variable slit	AEC
KB-18A (Fairchild)	Day strike	2.25 x 9.4	2.76 (perf)	250	300	KB-18	AC-1-4	3	2.8	40°00' x 180°00'	60 plus-x	1/100-1/4000	NA	AEC built to replace KA-71A

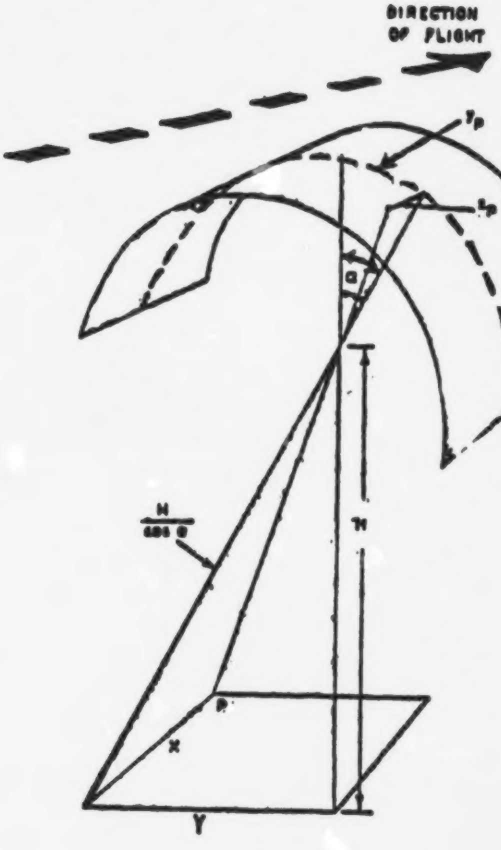

DIRECTION OF FLIGHT
y_p
z_p
α
H
$\frac{H}{\cos \theta}$
P
X
Y

FIGURE 3.2 OPERATION OF A PANORAMIC CAMERA

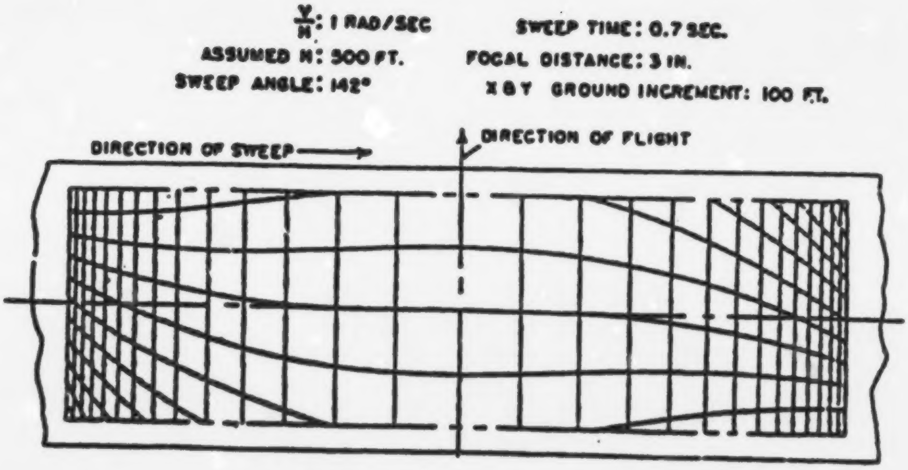

$\frac{V}{H}$: 1 RAD/SEC
ASSUMED H: 500 FT.
SWEEP ANGLE: 142°
SWEEP TIME: 0.7 SEC.
FOCAL DISTANCE: 3 IN.
X & Y GROUND INCREMENT: 100 FT.
DIRECTION OF SWEEP
DIRECTION OF FLIGHT

FIGURE 3.3 GEOMETRY OF A PANORAMIC IMAGE

field-of-view (in excess of 100 degrees) and some provide imagery from horizon to horizon. Thus, these cameras are very popular for photo reconnaissance and track recovery tasks.

Photographic interpretation of complex ground or ocean scenes is greatly facilitated with the use of multi-spectral images. As different features tend to exhibit unique spectral responses (signatures) the use of multi-spectral photography provides more information, and may identify features not necessarily seen using standard single band photography. Normal multi-spectral images are obtained by using optical bandpass filters in front of the camera lenses.

Multi-spectral imagery is attainable with either a multi-lens (usually four) camera or with four or more separate cameras, usually frame cameras. With a four lens camera only one film and four filter types are possible. With separate cameras any filter/film combination is possible, including the use of colour and colour IR films. Each system has advantages and disadvantages as shown in Table 3.6. Component selection for multi-spectral camera systems will depend on the user application.

Multi-spectral images may be viewed using additive colour viewing systems for manual or automatic interpretation. With this system, images are superimposed onto a cathode ray tube display with each image in a different colour. The

TABLE 3.6

COMPARISON BETWEEN FOUR LENS CAMERA AND FOUR CAMERA ARRAY

PARAMETER	FOUR LENS CAMERA	FOUR CAMERA ARRAY
Exposure	- usually 1 roll of film, although some units can use modified magazines with different rolls	- four separate film/filter combinations can be used because of separate magazines
	- four-slit focal plane shutter assures identical exposure time and identical spatial positioning of all images relative to the principal point	- between-the-lens shutters can cause synchronization errors in terms of exposure time and time lag between actual exposure on each film (focal plane shutters can also be used but the same problems occur)
	- lenses are aligned in a single body thus maintaining orthogonality of optical axis and focal plane	- difficult to maintain precise vertical alignment between individual cameras
	- only one image motion compensation device necessary	- four image motion compensation devices needed
	- exposure changes can only be made using the diaphragm of each lens	- exposure can be varied with both aperture and shutter timing of each camera allowing a wider latitude for scene brightness
Processing	- only one film to process therefore detailed printing correction procedures necessary	- processing of each roll can be tailored so that the individual images are optimized
Viewing	- composite multispectral viewer can be made compatible with multispectral camera	- each film record must be manually aligned with respect to each other for each frame used

choice of colours and the relative intensities of the images are under the operator's control. Both optical and electronic systems have been made, and each have certain advantages. Multi-spectral images may also be used for computer analysis, which requires the individual images to be scanned with a densitometer; the density values for a single object from all the images constitute a vector parameter or spectral signature for the object.

A number of filters are available for use, and their selection is again dependent on the particular application. The characteristics of some filters are given below.

a) Absorption filters

Absorption filters are of two types: those which block shorter wavelengths, known as long wavelength pass filters (these are very efficient); and those which block both longer and shorter wavelengths, known as bandpass filters (much less efficient). There are no absorption filters which block long wavelengths only. Absorption filters are also known as thin film or dielectric filters and are sensitive to incidence angle. The variety of these filters is limited with regard to the wavelength selectivity. These filters are manufactured in either a glass or gelatin format. The most commonly known are the Kodak Wratten filters, although Corning, Schott and Gen also manufacture them.

b) Interference Filters

These filters are sensitive to incidence angle although there are virtually no restrictions in terms of wavelength selection. They work on the principle of reflecting the unwanted wavelengths and transmitting the selected wavelengths, and are comprised of alternating layers of high and low refractive-index dielectric materials. When used to remove unwanted transittance they are called blocking filters.

c) Colour Compensating Filters

These filters modify the colour balance in colour and colour infrared films which results in a practical, low cost method of enhancement. Filters are available in red, blue, green, cyan, yellow, and magenta and each affects one or two of the colour layers. Their effect depends on the density of the filter being used.

d) Polarization Filters

These filters can be used to penetrate haze, thereby increasing scene contrast and image resolution. There have also been suggestions that these filters may have some use in formulating a polarization spectral signature which could be useful as another method of discriminating ground features. Very little data is available on polarizing filters.

The detection and identification of a target is dependent on certain parameters: spatial resolution, radiometric fidelity, and spectral resolution. The spectral resolution in a multi-spectral camera system is controlled by the filter bandwidths and is inversely proportional to the system's sensitivity. The resolution required to detect or identify an object is dependent on the object's size and shape as well as the object-to-background contrast ratio. In general, a higher contrast resolution is required to identify a target than to merely detect it. Interpretation of ground features through aerial photography is accomplished by evaluating variations in size, shape, texture, pattern, shadow, and tone (or colour). Thus, the ability of a photographic system to faithfully reproduce these data in relation to the object characteristics, consistently from mission to mission, is extremely important. In fact, calibration and quality control are probably the greatest problems in photographic systems, especially when interpretation or target detection is dependent on quantitative spectral and temporal signatures.

Aerial photography may be severely affected by atmospheric scattering and absorption. Scattering and absorption are wavelength dependent and also vary with atmospheric levels. Atmospheric scattering most strongly affects the shorter wavelengths in the blue portion of the spectrum. These effects become more pronounced with altitude.

The geometry of aerial photography also affects the quality of information recorded on the photograph. Figure 3.4 illustrates the geometry, showing the relationship between solar altitude, azimuth and incidence angles. Changes in the solar altitude angle will cause changes in shadow lengths; light reflected from shadowed areas will normally be scattered light, and is therefore wavelength dependent. Both solar altitude and azimuth are significant in determining the reflectance from an object. As the incidence angle increases, the atmospheric path length increases, causing variations in exposure across the image.

Photographic scale provides an indication of the level of information contained in a photograph and is given by:

$$\text{Scale} = \frac{\text{Camera Focal Length}}{\text{Altitude above ground}} = \frac{1}{\text{Scale Factor}} \qquad (3.1)$$

The effects of focal length and altitude on scale and ground coverage are shown in Figures 3.5 and 3.6 respectively, for vertical cameras. In the case of non-vertical photography or when the earth's curvature has a significant effect (at very high altitudes) the formulation and use of scale numbers is more complex. A better measure of information content of a photograph is its ground resolution, or the ground dimension equivalent to one line at the limit of resolution given by:

$$\text{Ground Resolution (metres)} = \frac{\text{Scale Factor} \times 10^{-3}}{\text{Resolution (lines/millimetre)}} \qquad (3.2)$$

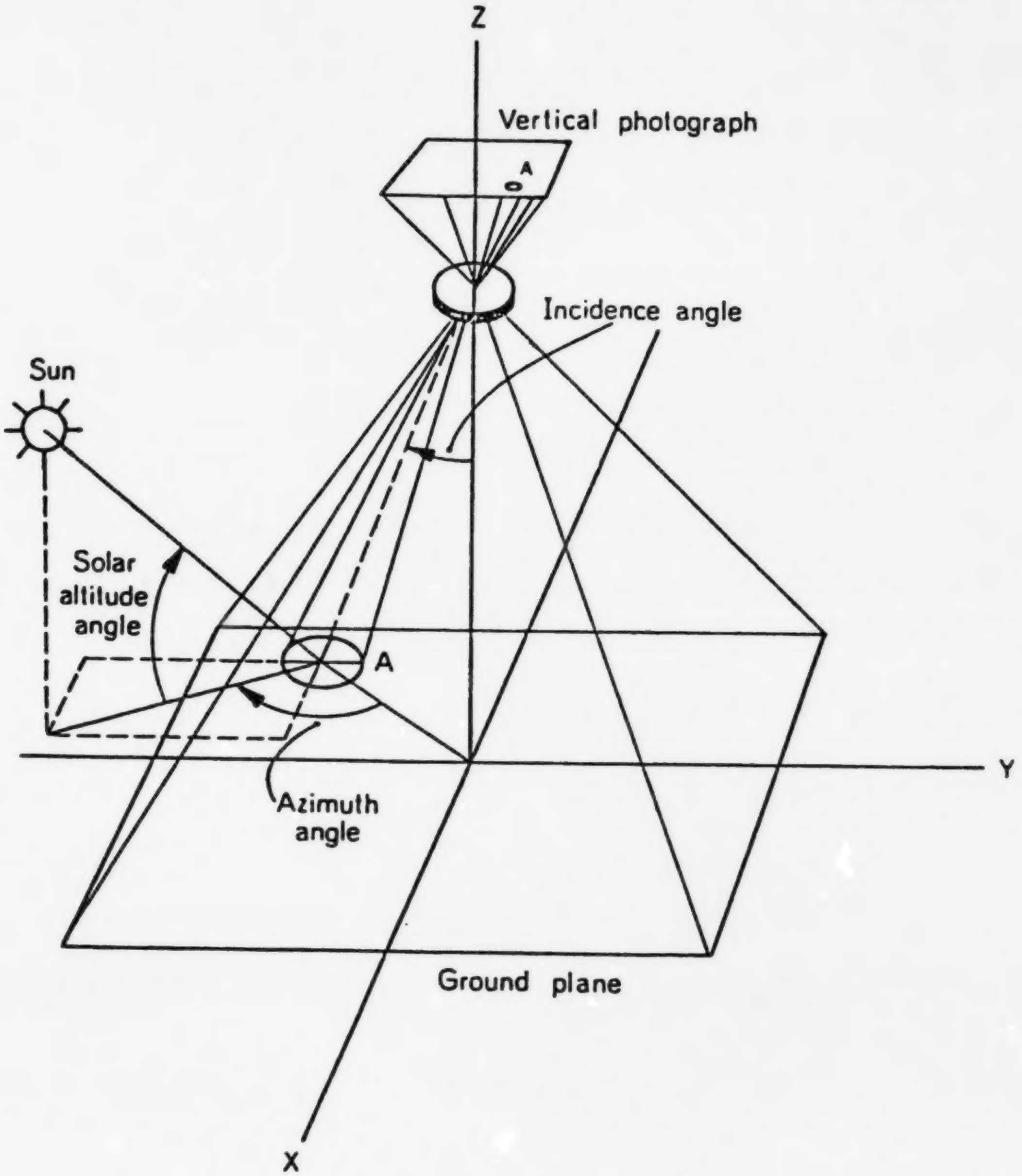

Z
Vertical photograph
A
Incidence angle
Sun
Solar altitude angle
A
Y
Azimuth angle
Ground plane
X

FIGURE 3.4 GEOMETRY OF VERTICAL PHOTOGRAPHY SHOWING ANGLES INVOLVED IN SPECTRAL REFLECTIVITY EXPERIMENT (Lilles & Kiefer, 1979)

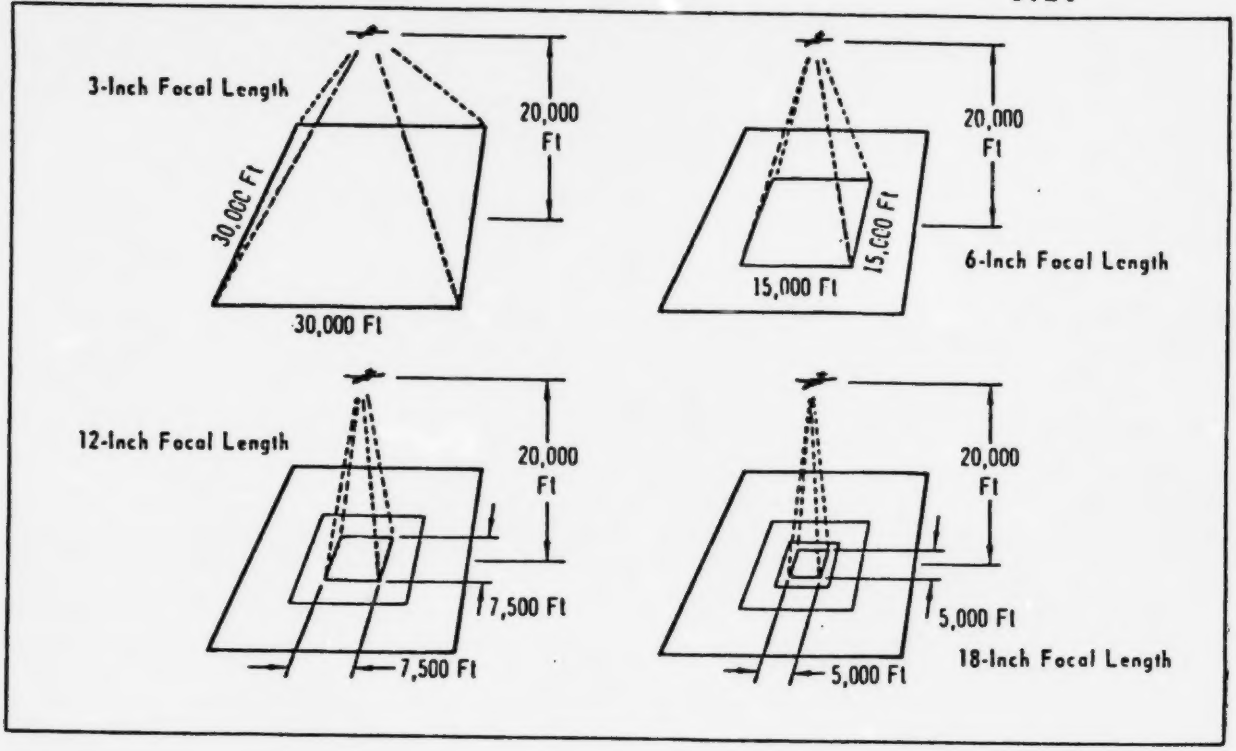

3-Inch Focal Length
20,000 Ft
30,000 Ft
30,000 Ft
20,000 Ft
15,000 Ft
15,000 Ft
6-Inch Focal Length
12-Inch Focal Length
20,000 Ft
7,500 Ft
7,500 Ft
20,000 Ft
5,000 Ft
5,000 Ft
18-Inch Focal Length

FIGURE 3.5 EFFECT OF FOCAL LENGTH ON SCALE AND GROUND COVERAGE

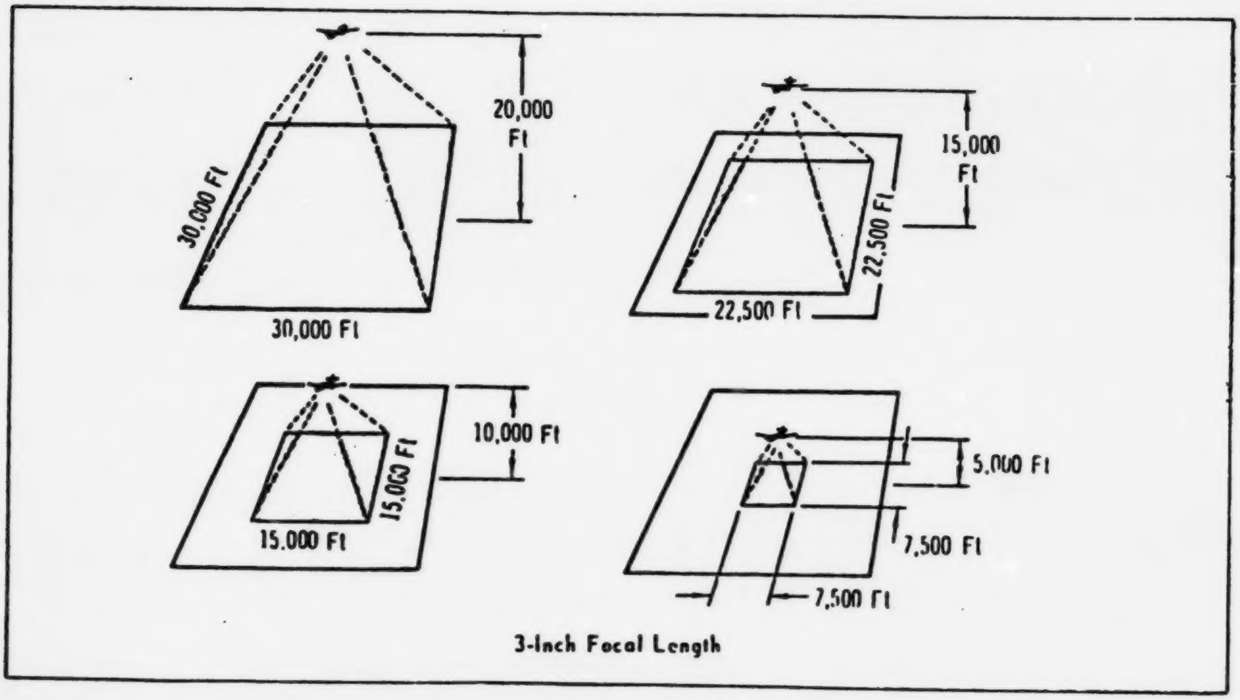

20,000 Ft
30,000 Ft
30,000 Ft
15,000 Ft
22,500 Ft
22,500 Ft
10,000 Ft
15,000 Ft
15,000 Ft
5,000 Ft
7,500 Ft
7,500 Ft
3-Inch Focal Length

FIGURE 3.6 EFFECT OF ALTITUDE ON SCALE AND GROUND COVERAGE

It can be seen from the above that the most desired combination of broad areal coverage and fine ground resolution are not compatible. Lower resolution is normally traded off in order to obtain larger areal coverage and smaller scale. For effective interpretation, high contrast ratios (ratios of target to background image brightness) and aspect ratios (ratios of object length to width) are desired. The measurement of object heights on a single print is sometimes feasible from the shadow length and knowledge of the sun elevation angle. However, to determine heights accurately, stereoscopic photo coverage is necessary.

Aerial photography has been used for a variety of purposes including oil pollution monitoring. It may be used as the sole sensing system or to support measurements made with other sensors, providing "ground truth" or "surface verification" information. Its weather dependence precludes its use as a stand-alone sensor for many applications. With the advent of all weather imaging systems, the support role has been the primary one. A summary of the advantages and disadvantages of aerial photography is given in Table 3.7.

3.1.2 Non-Photographic Sensors

Non-photographic sensing systems can be used to sense the ultraviolet, visible and infrared portions of the electromagnetic spectrum. They are applicable to spectral regions where photography can be used and may extend beyond the near visible and thermal infrared regions. The sensors

TABLE 3.7

AERIAL PHOTOGRAPHY ADVANTAGES AND DISADVANTAGES

ADVANTAGES	DISADVANTAGES
Ease of interpretation	Dependent on lighting conditions
Can provide spectral or colour information	Weather dependent
Relatively low cost	Exhibits radial distortion
High resolution	Difficult to undertake temporal spectral quantitative measurements
Readily available	Information not available on real time basis
Rapid data acquisition	
Variety of scales	
Stereoscopic coverage	
Flexibility of film type	
Versatility in terms of format, cameras, and vehicle selection	

utilized in these regions can be divided into passive and active systems. The radiometer and its more complex forms, the various types of scanners, and image tube sensors are the principal systems in the passive group. The active sensors in this group employ lasers as the energy source although the addition of high intensity light sources also constitute a form of active energy source.

3.1.2.1 Radiometers

A radiometer is a passive non-imaging device which measures the absolute value of the energy emitted and/or reflected from an object. A radiometer may be sensitive to energy from the ultraviolet to the far infrared region (0.2 to 14 μm) depending upon the type of sensing element being used. Systems that measure radiation from 0.3 to 1 μm are also called photometers. This division is a natural one, dictated by the type of radiation received (reflected radiation in the 0.3 to 1.2 μm region and thermally emitted radiation at wavelengths greater than 1.2 μm).

Both absolute and relative infrared radiation levels may be obtained with a radiometer. For absolute measurements, the received radiation must be compared with a known reference level. The form of reference radiation level used determines the ultimate accuracy of a radiometer. The detector itself (DC radiometer) or a radiation chopping system (AC radiometer) can be used to provide the reference radiation level. A chopping system is preferred for absolute measurements. The AC chopper-mirror type system most commonly used, alternately measures incoming radiation and that from reference blackbodies at known constant temperatures (controlled either thermostatically or electronically).

As the infrared region begins, just outside the visible limits, at about 0.75 μm, infrared radiometers are normally designed to observe thermal emission from a scene. Day time operation for thermal profiling is confined to the atmospheric windows of 4.5 to 5.5 μm and 8.5 to 13.5 μm. Night time operation is confined to the longer wavelength region of 8.5 to 13.5 μm. Such systems cannot operate when there is cloud cover or fog.

The mechanism used to detect energy between ultraviolet and long infrared wavelengths varies. Photon energy is inversely proportional to wavelength. Thus, in the high energy portion of the spectrum, the photo emissive effect is used, as energies are sufficient to free electrons from the surface of some materials. Beyond 1 μm, however, the photon energies of materials are too small to produce the photo emissive effect. At these longer wavelengths, materials are used, in which the photons are absorbed by bound electrons. In this case, photo conducive, photo voltaic, and photo electromagnetic effects are used.

The sensitivity of a detector is dependent on the temperature of the reference radiation source, the bandwidth, the receiving area of the detector, the wavelength, and the chopping frequency.

Radiometers such as the Barnes precision radiation thermometers (PRT-5 and PRT-6) provide point measurements along a trace line. As the aircraft moves, measurements are made directly beneath the plane. A block diagram of a typical airborne radiometer is shown in Figure 3.7 while Figure 3.8 illustrates the output.

Readings from a radiometer operating in the thermal emission range of the spectrum can be converted to a temperature, T, if the emissivity, e, of the object sensed is known ($W = \sigma e T^4$, where W is the radiometer measurement and σ is the Stefan-Boltzman Constant). Alternatively, if the temperature of the object is known, its emissivity can be determined through the above relationship. Table 3.8 gives examples of generic radiometers.

The energy collection system for radiometers differs according to the type of work required. If the object is some distance from the probe, a directional capability is necessary. The collection system directs the energy onto an energy sensitive detector. Lenses are used to direct the energy in the visible and near IR regions, whereas mirrors are used in the thermal emission region to direct the incoming radiation. An optical mirror system will work equally well for thermal, visible, or ultraviolet energy, if proper detectors are used.

The detector is a transducer which converts the incoming radiation into an electrical current. Two common

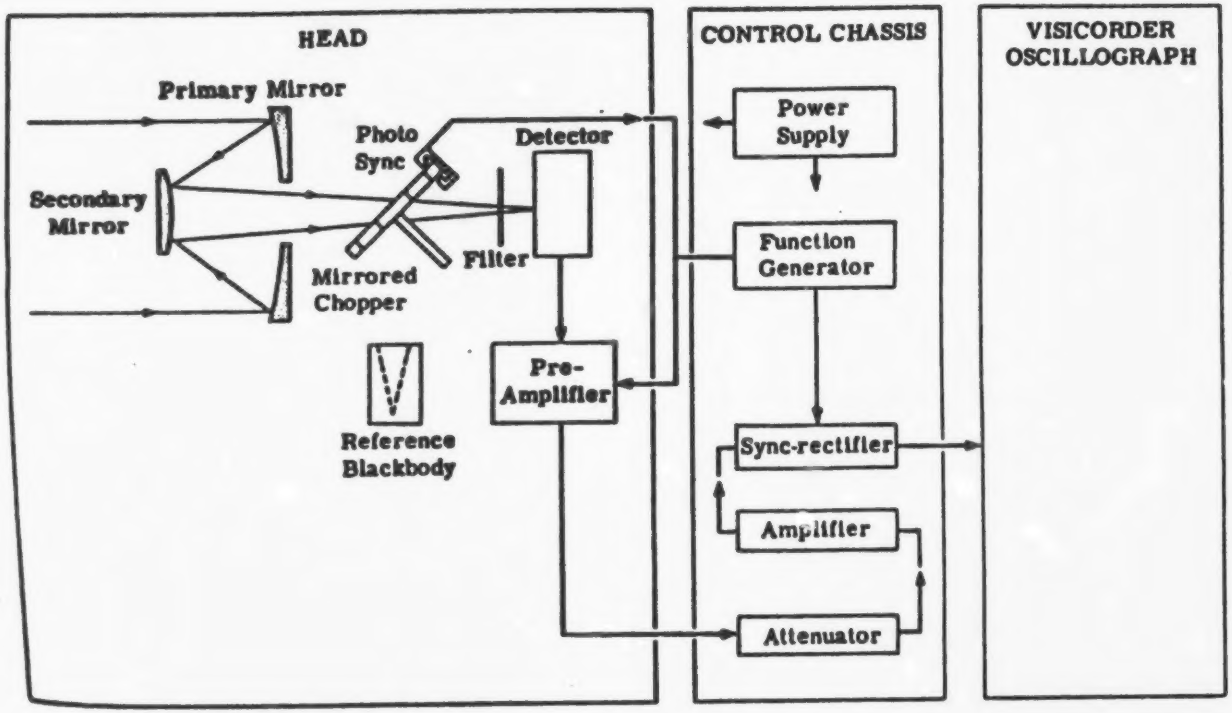

HEAD
Primary Mirror
Secondary Mirror
Photo Sync
Mirrored Chopper
Filter
Detector
Reference Blackbody
Pre-Amplifier
CONTROL CHASSIS
Power Supply
Function Generator
Sync-rectifier
Amplifier
Attenuator
VISICORDER OSCILLOGRAPH

FIGURE 3.7 BLOCK DIAGRAM OF AN AIRBORNE RADIOMETER

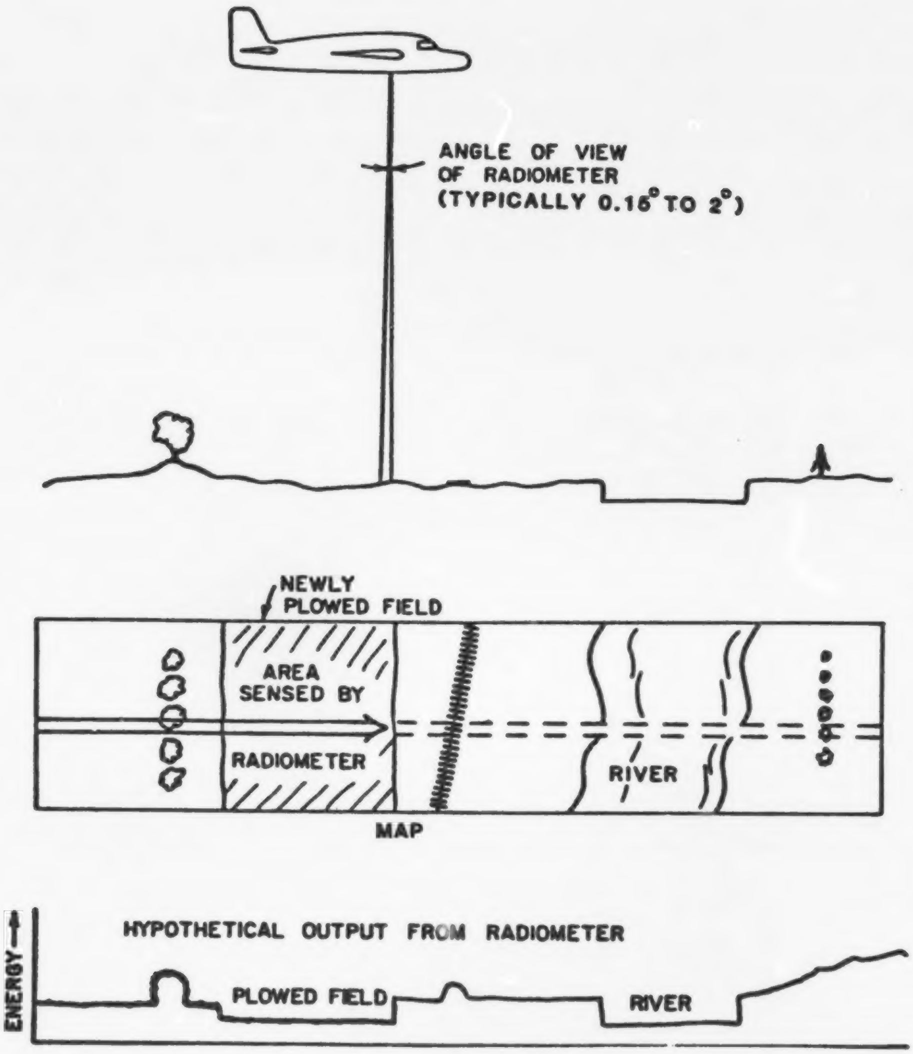

ANGLE OF VIEW
OF RADIOMETER
(TYPICALLY 0.15° TO 2°)
NEWLY
PLOWED FIELD
AREA
SENSED BY
RADIOMETER
RIVER
MAP
ENERGY
HYPOTHETICAL OUTPUT FROM RADIOMETER
PLOWED FIELD
RIVER

FIGURE 3.8 BASIC RADIOMETER OPERATION (Richason, 1978)

TABLE 3.8 COMPARISON OF RADIOMETERS, 1.4-225 GHz (Lintz & Simonett 1976)

FREQUENCY (GHz)	1.4	8-12	10	13.4	19.4	22.235	32.4	60	94	138	225
Special Comment	Atmospheric absorption negligible	Atmospheric absorption slight	Atmospheric absorption slight	Profiler	Imager ±50° scan	Absorption line, H_2O	Window	Temperature(a) profiling, O_2 complex	Window absorption high	Window	Window slightly opaque
Antenna Type	Two-dimensional phased array	60 ft disk	Lens-horn	Lens-horn	Phased array	Lens-horn	Lens-horn	Dual-pad	Long-horn	Convex lens and horn	Convex lens and horn
Beam width 3dB (degrees)	16	0.06	5	5	3 nominal	5	5	-	0.5-1.5	0.3	0.3
Polarization	Linear		Linear	Dual	Dual	Linear	Dual	-	Dual	Either land based	Either land based
Calibration	Noise source	Nitrogen	Noise source	-	Nitrogen Helium	Noise source	Noise source	Cyrogenic	-	VL(b)	VL
Amplifiers	Mixer, IF	Maser, rF	Mixer, IF	Mixer, IF	-	Mixer, IF	Mixer, IF	Multisection mixers	Mixer, IF	TWT(c)	TWT
Noise figure (dB)	6	0.06	5.5	-	6	8.5	10	-	-	20	26
ΔT(K)rms	±0.26	±0.033	±0.14	±1	-	±0.8	±0.5	-	±1	±0.3	±1.0
Integration time (sec)	1	2	1	0.5-1.5	1	1	1	-	0.5-1.5	10	10
Application	ERP(d)	RA(e)	ERP	ERP	ERP	ERP	ERP	ERP satellite surveys	EM(f)	RA	RA

(a) No firm data available: radiometers are designed and operational
(b) VL blackbody thermal closure with variable heat source
(c) TWT Travelling-wave tubes
(d) ERP Earth Resource Program (NASA)
(e) RA Radio astronomy
(f) EM Earth materials: soil, snow and ice

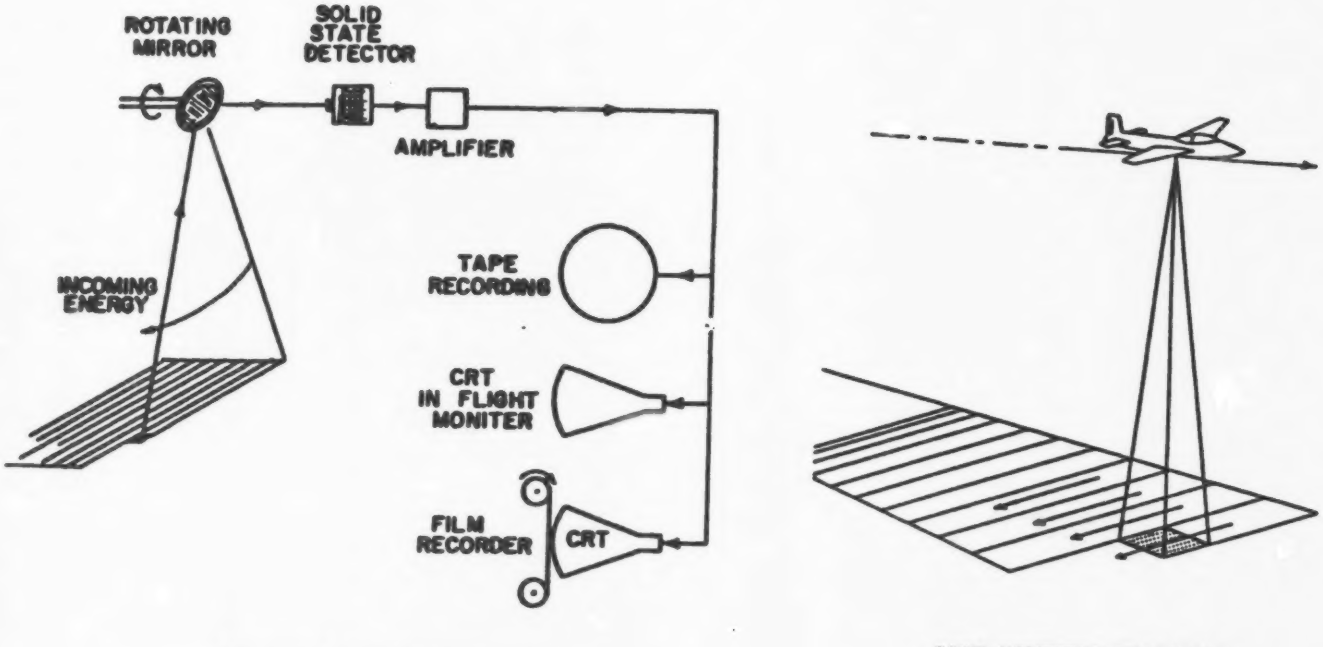
3.32

detectors used are photo resistors and photo diodes. Different detectors are sensitive to various spectral ranges and those operating in the thermal emission region are cooled during operation to reduce thermal noise and thus increase sensitivity. To detect energy within a specified spectral band, use is made of either a filter to block undesired energy or a diffraction grating to bend and "fan-out" the incoming energy. When the detector is placed in the proper geometric position within the fan, it will sense only in the spectral range of interest. No filter or grating systems are necessary to record the total incoming energy across the entire range of the detector's sensitivity.

3.1.2.2 Line Scanners

In these systems, scanning is performed by mechanical means. If a radiometer is made to sweep from side to side as the aircraft moves over the ground, a series of cross-profiles would result as shown in Figure 3.9. These cross-profiles are made up of a series of instantaneous fields of view which determine the resolution of the system and are defined by the size of the collection optics. The scanner mechanics can be separated into three categories (Figure 3.9): energy collection system, detection system, and data recording system.

The collection system consists of a front surfaced mirror mounted on a shaft that is oriented parallel to the flight line. The across-track motion of the spinning mirror, and along-track motion of the aircraft, produces a continuous


ROTATING MIRROR
SOLID STATE DETECTOR
AMPLIFIER
INCOMING ENERGY
TAPE RECORDING
CRT IN FLIGHT MONITER
FILM RECORDER
CRT

SCHEMATIC OF SCANNING UNIT

LINE-SCANNING TECHNIQUE
USED BY MECHANICAL SCANNERS

FIGURE 3.9 IMAGING RADIOMETER (SCANNER) OPERATION

raster of swaths perpendicular to the flight line. Typically the mirror scans outward on each side to about 60°, providing approximately 120° of angular coverage as shown in Figure 3.10. The image distortion produced by scanning is shown in Figure 3.10.

Received energy is directed by the mirror on to a solid-state detector, where it is converted into an electrical impulse proportional to the intensity of the radiant energy. The detector is usually a photo-electric tube containing indium antimonide or a similar compound. Most of the detectors must be kept at temperatures close to 0°K by cryogens, such as liquid nitrogen or helium. This minimizes the detector noise, improving the signal-to-noise ratio.

After amplification, the electrical impulse is usually viewed in-flight on a cathode ray tube (CRT) display and is simultaneously recorded on electromagnetic tape for subsequent viewing on a CRT. It may also be recorded as an image on 70 mm film for more detailed analysis. The resultant black and white image contains several grey levels, with each level representing a discrete temperature range. On a positive image, the darker tones indicate cool areas, while lighter tones represent warmer areas.

Multi-spectral scanners differ from thermal scanners, spectrometers, and radiometers in that several wavelength bands (ultraviolet, visible, and/or thermal) are imaged simultaneously. Multi-spectral imagery provides greater

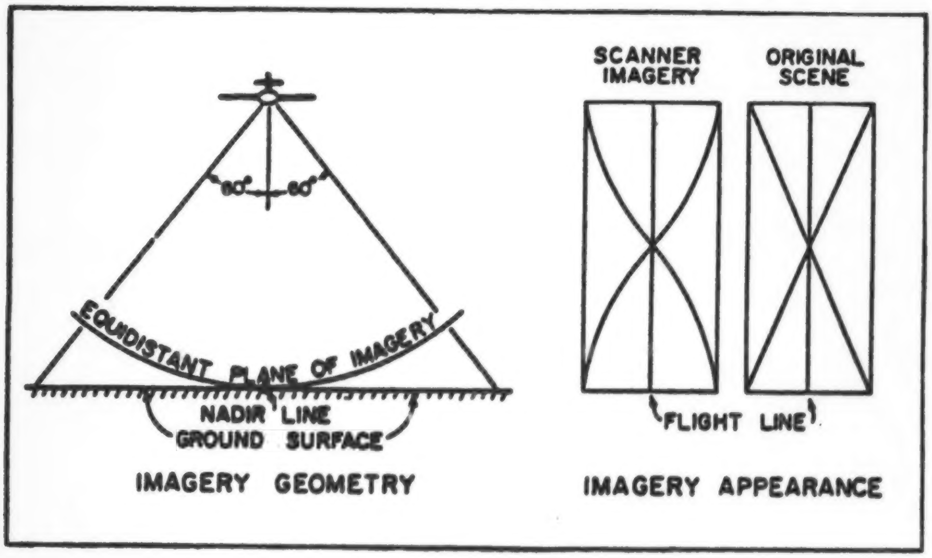

SCANNER IMAGERY
ORIGINAL SCENE
60°
60°
EQUIDISTANT PLANE OF IMAGERY
NADIR LINE
GROUND SURFACE
FLIGHT LINE
IMAGERY GEOMETRY
IMAGERY APPEARANCE

FIGURE 3.10 AIRBORNE SCANNER GEOMETRY

interpretation capability by allowing spectral signature analysis.

The mechanics of the multi-spectral unit are similar to those of thermal and other scanners, with an additional separation assembly located between the energy collection system and the detector system (Figure 3.11). The purpose of this separation assembly is to split the incoming energy with a prism or diffraction grating into smaller bands which are then passed onto the detector system. The prism or diffraction grating refracts the incoming energy, with the shortest wavelength being refracted the greatest amount (Figure 3.12). Individual detectors are geometrically placed in this path to sense the energy in each wavelength band. A multi-spectral unit is usually referred to as an "n" channel unit, where "n" equals the number of detectors. An image is usually produced for each channel. By assigning a different colour to each channel and superimposing the images, a composite colour picture can be produced.

One of the airborne systems developed by the Bendix Corporation provides 24 channels in the 0.34 to 12 μm spectral region. The channels were selected on the basis of potential applications and atmospheric absorption windows (Figure 3.13). For example, geological specimens emit radiant energy in the 300^{O}K black-body range between 5 and 20 μm with a peak at about 10 μm. Samples of granite and obsidian show pronounced emissivity variations in the 8 to

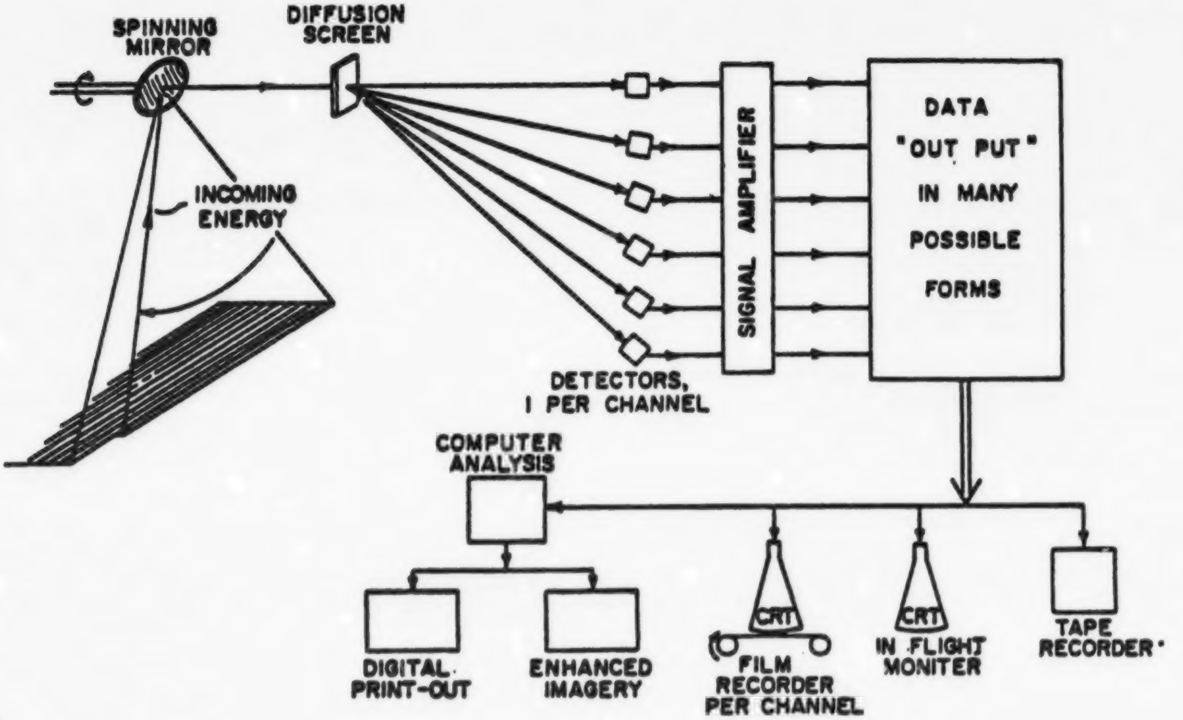

SPINNING MIRROR
DIFFUSION SCREEN
INCOMING ENERGY
SIGNAL AMPLIFIER
DATA "OUT PUT" IN MANY POSSIBLE FORMS
DETECTORS, I PER CHANNEL
COMPUTER ANALYSIS
CRT
CRT
DIGITAL PRINT-OUT
ENHANCED IMAGERY
FILM RECORDER PER CHANNEL
IN FLIGHT MONITER
TAPE RECORDER

FIGURE 3.11 MULTISPECTRAL SCANNERS BLOCK DIAGRAM

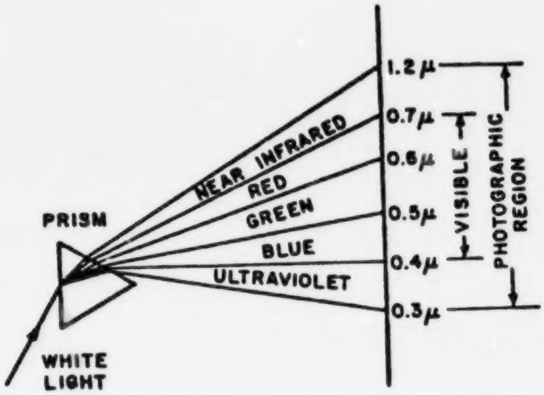

1.2µ
0.7µ
0.6µ
0.5µ
0.4µ
0.3µ
NEAR INFRARED
RED
GREEN
BLUE
ULTRAVIOLET
VISIBLE
PHOTOGRAPHIC REGION
PRISM
WHITE LIGHT

FIGURE 3.12 PRISM OR DIFFRACTION GRATING

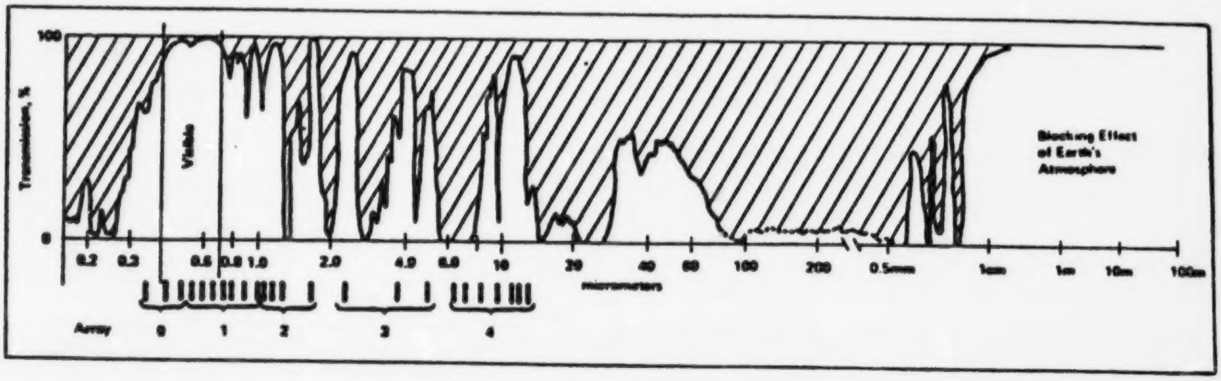


FIGURE 3.13 SPECTRUM UTILIZATION ON BENDIX CORPORATION MULTI-SPECTRAL SCANNER (Bendix Corporation)

11 μm region, requiring narrow bands within this region, to allow discrimination. Ice, with a temperature of 240^{o}K to 272^{o}K emits energy around 11 μm with an emissivity of between 0.7 and 1. The selected channels are shown in Table 3.9. Two very narrow channels (23 and 24) are provided in the near infrared region to estimate the amount of water vapour between the scanner and the target.

In pushbroom scanners, imaging is achieved by sequential electronic sampling of a solid state sensor array. The array is illuminated optically from the ground and the vehicle's velocity causes the image path to move across the earth's surface. A record of terrain radiance is obtained by repeated sampling of the array. That is, aircraft motion provides one direction of scan and electronic sampling of the detectors in the cross track dimension provides the orthogonal scan component to form an image. The detector array is sampled at the appropriate rate to produce contiguous lines. One array is typically used for each spectral channel.

Because there are no mechanical devices needed for the imaging process, all mechanical disturbances are eliminated, resulting in relatively high resolution imagery. In addition, the precision geometry of the linear arrays provides accurate band-to-band registration and the accurate location or mapping of terrain features. Greater signal power is also achieved as a result of the large area of the

TABLE 3.9

BENDIX AIRBORNE MULTI-SPECTRAL SCANNER CHANNEL DESCRIPTIONS

Array Number	Channel Number	Bandwidth (micrometers)	Detector	Absolute Calibration Source[a]
0	1	0.34– 0.4	photomultiplier	UV/V/IR
	2	0.4 – 0.44	photomultiplier	UV/V/IR
	3	0.46– 0.5	photomultiplier	UV/V/IR
1	4	0.53– 0.57	silicon	UV/V/IR
	5	0.57– 0.63	silicon	UV/V/IR
	6	0.64– 0.68	silicon	UV/V/IR
	7	0.71– 0.75	silicon	UV/V/IR
	8	0.76– 0.80	silicon	UV/V/IR
	9	0.82– 0.87	silicon	UV/V/IR
	10	0.97– 1.05	silicon	UV/V/IR
2	11	1.18– 1:30	germanium	UV/V/IR
	12	1.52– 1.73	germanium	UV/V/IR
3	13	2.1 – 2.36	indium antimonide	UV/V/IR
	14	3.54– 4.0	indium antimonide	blackbodies
	15	4.5 – 4.75	indium antimonide	blackbodies
4	16	6.0 – 7.0	mercury-doped germanium	blackbodies
	17	8.3 – 8.8	mercury-doped germanium	blackbodies
	18	8.8 – 9.3	mercury-doped germanium	blackbodies
	19	9.3 – 9.8	mercury-doped germanium	blackbodies
	20	10.1 –11.0	mercury-doped germanium	blackbodies
	21	11.0 –12.0	mercury-doped germanium	blackbodies
	22	12.0 –13.0	mercury-doped germanium	blackbodies
2	23	1.12– 1.16	germanium	UV/V/IR
1	24	1.05– 1.09	silicon	UV/V/IR

[a] *UV/V/IR = ultraviolet/visible/near-infrared.*

focal plane from which the signal is continuously gathered (increasing the "dwell time" available to record the signal). This improved instrument sensitivity is used to increase the radiometric accuracy, improve geometric resolution, and provide narrower spectral bands.

Pushbroom scanners, in contrast to the scanners discussed thus far, do not use moving optics to achieve scanning. The technology is relatively new and the operation of this type of scanner has so far been restricted to visible and reflected infrared regions of the spectrum. A thermal infrared (TIR) channel has been included in a pushbroom type scanner suggested for remote sensing of oil spills and ocean pollution by satellites (Alvarado, 1980).

Thermal IR and multispectral imagery have been used in ice measurements, geological mapping, oceanographic surveillance, and oil spill detection and monitoring. Scanners have several advantages and disadvantages in comparison to photographic systems. The advantages include:

1) Measurements can be made outside the visible spectrum;
2) A greater flexibility and control exists in selecting several narrow spectral bands;
3) The output is such that it can be displayed in real time, readily transmitted, recorded and/or processed;
4) The data may be analyzed in a variety of formats;

5) The systems have a wider dynamic range and greater sensitivity;
6) The data can be easily calibrated, allowing quantitative analysis and comparison;
7) Thermal scanners which detect naturally emitted radiation can operate day or night.

The disadvantages include:

1) The spatial resolution is poor compared with photographic systems;
2) The systems are more bulky;
3) Scanner images are considerably more susceptible to aircraft motion (Figure 3.14 shows the types of distortion possible); and
4) The scale of the scanned image varies laterally across the flight line (for many applications this may be unimportant).

Like photographic systems, scanners are weather dependent (although certain spectral bands can be used in light cloud conditions) and are subject to lighting conditions. In the case of thermal imagery the temperature scale (hence grey tones) of the image may vary along the flight line due to changes in the terrain thermal conditions. Also, temperature variations in the intervening atmosphere can create problems in interpretation and quantifying data on a thermal image.

There are several commercially available scanning systems. Table 3.10 gives an outline of commercially

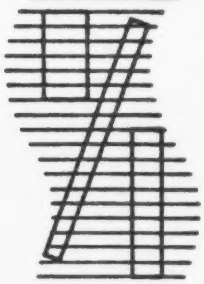
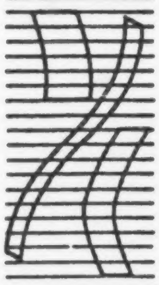
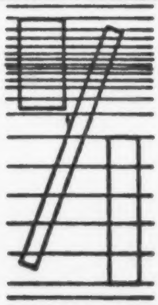
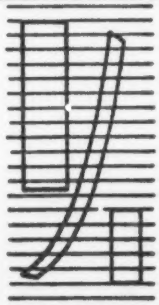
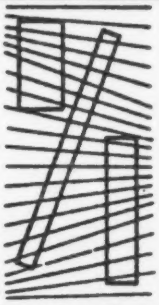
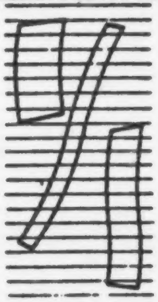
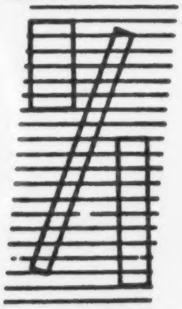
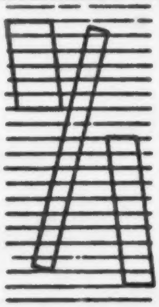
	Aircraft Motion	Scan Mode	Recording Mode	Identification
Direction of Flight ⟶	**Roll**	 Scan Raster Displaced Sideways	 Images Displaced Sideways	Wavy appearance of straight lines (roads). Cyclic displacement of imagery synchronized with the aircraft rolling.
	Pitch	 Uneven Scanline Spacing	 Images Compressed and Stretched	Compresses and elongates images of objects (occurs less frequently than roll).
	Yaw	 Scan Lines Skewed	 Image Edges Skewed or Displaced	Compresses and elongates images of objects laterally across the film. Wedging takes place and image edges are skewed.
	Drift	 Scan Lines Displaced Uniformly	 Images Displaced Uniformly	Rectangles are distorted into parallelograms. Angle of distortion is approximately equal to the drift angle. Under normal conditions of drift (less than 10°) this distortion will be quite small.

FIGURE 3.14 IMAGE DISTORTIONS ON INFRARED SCANNER IMAGERY RESULTING FROM AIRCRAFT MOTION

TABLE 3.10 EXAMPLES OF SOME COMMERCIALLY AVAILABLE AIRBORNE INFRARED SCANNERS

MANUFACTURER	SCANNER MODEL	METHOD OF SCANNING	SCAN TIMES/SEC	SCAN WIDTH (DEGREES)	RESOLUTION ELEMENT (MRAD)	TYPE OF COLLECTING OPTICS	FOCAL LENGTH (cm)	F/NO.	EFFECTIVE COLLECTOR AREA (cm^3)	METHOD OF RECORDING	V/H MAX	$NE\Delta T$ °K	WEIGHT	POWER	TYPE OF DETECTOR AVAILABLE
Texas Instruments	RS-310	4-sided Prism	200	90	1.5	Reflective	15	2.1	40.5	Film	0.3		96.5	dc:28V 9 amp	S-13 μm Silicon
TRW Hawker	Siddeley			12	1.5					Film	0.75	0.5	25	dc:28V 6 amp	Hg:Cd:Te
Daedalus	DEI-100	Double-faced 45° mirror	120	120	2.5	Newtonian	15	1.2	45	Tape recording Film optional	0.3	0.3	65	dc:28V 5 amp	μm In:Sb Pb:Sn:Te
Daedalus	DS-1200	45° mirror	80	77	2.5	Newtonian	15	1.2	40.7	Tape recording Film optional	0.2	0.3-0.2	85	dc:28V 5 amp	8 μm In:Sb Pb:Sn:Te
HRB Singer	Reconofax VI	Double-faced 45° mirror	370	120 or 140	2 or 3	Newtonian	15	1.8	21.0		0.75-4.1	0.5-0.7	75	ac: 3 phase 115V 400 Hz surge, 1.5 amp steady	Ge:Hg In:Sb
HRB Singer	Reconofax XIII A	4-sided Prism	400	120	1 and 2 mr (in same dewar)	Reflective	10	1.5	35	Film	1.6 rad/sec	0.3 at 1 mr 0.2 at 2 mr	135	28V DC @ 4.3 amps, 115VAC 400 Hz, 3 phase 400 Watts	Hg:Cd:Te
Bendix T/M	LN-3	45° Prism	100	120	2.5	Dall-Kirkham	30	4	45.5	Film Tape Recorder Optional	0.25	0.3-0.2	55	dc:28V 5 amp	S-11 μm S-13 μm In:Sb Hg:Cd:Te

available infrared scanners and Table 3.11 multi-spectral line scanners.

3.1.2.3 Image Tube Systems

These are non-scanning imaging systems which operate in the ultraviolet, visible and infrared regions. They are also called electro-optical or television sensors. They normally have narrow fields of view. The image tube is actually the detector of the system. An optics package collects the incoming radiation and focuses it on the image tube detector. The detector is an array of electronic detectors whose output is in a raster format. The output is used to modulate the beam intensity on a cathode ray tube producing a real-time image. The image can be recorded on video tape or made into a hardcopy freeze-frame image.

There are various types of imaging tubes, each with its own special set of characteristics. All use a focused electron beam to scan the image. This beam is generated in an electron gun, accelerated, focused in an electronic lens, and deflected, either electromagnetically or electrostatically, into a scanning pattern.

The sensitivity and resolution of available image tube systems are variable and each type is often characterized by usage. Some image tubes are used as the sole sensor while others are utilized as components in other sensor systems, or as the means for transferring the image data.

TABLE 3.11 EXAMPLES OF SOME COMMERCIALLY AVAILABLE MULTISPECTRAL SCANNERS

MANUFACTURER	SCANNER MODEL	[illegible]	METHOD OF SCANNING	SCAN LINES/ SECOND	SWATH WIDTH DEGREES	RESOLUTION [illegible]	TYPE OF COLLECTING OPTICS	FOCAL LENGTH & F/NO.	DIAMETER OF APERTURE	EFFECTIVE APERTURE AREA	ROLL COMPENSATION	CALIBRATION IN FLIGHT	METHOD OF RECORDING	METHOD OF SPECTRAL SEPARATION	TOTAL WEIGHT (LESS RECORDER)	POWER	SPECTRAL BANDS (μm)
Bendix Corp. Aerospace Systems Division	Multispectral Data System	0.16	Single 45° mirror	[illegible]	80	2.0	Dall-Kirkham	1,142 mm f/5.0	228 mm	38,100 mm²	Signal ± 8°	Blackbody, Q-H Lamp, Sky ref.	24 track digital magnetic tape	Diffraction Grating	1,273 kg (2,800 lbs)	1,100 W 28VDC [illegible]	24 bands range 0.34-13.0
Daedalus Enterprises	Daedalus Spectrometer	0.2	Single 45° mirror	80	77	2.5	Paraboloidal Newtonian	182 mm f/2	127 mm	4,000 mm²	Signal ± 10°	Q-H Lamp	7 track magnetic tape	Prism	54.3 kg (120 lbs)	132 W 28VDC	10 bands range 0.38-1.10
[illegible] Ind., Inc.	[illegible]	0.1	Conical	80	64.3	2	Cassegrain		180 mm		No stabilized mount (optional)	Lamp	Magnetic tape	Prism/Beam splitter	79 kg (175 lbs)	300 W 28VDC	8 bands range 0.5-12.6
Texas Instruments	RS-14	0.2	4 sided mirror		80	10.3	Dall-Kirkham	254 mm f/2.7		3,740 mm²	Signal ± 8°	Blackbodies Q-I Lamp	CRT with film	Dichroic	120 kg (264 lbs)	100 W 28VDC 675 W 115 VAC	7 bands only two can be used at one time

The ability of an image tube to distinguish fine detail is primarily a function of the effective beam diameter as it is electronically scanned across the CRT screen, and the bandwidth of the video signal. With video bandwidths over 1 MHz and a sufficient number of scan lines, the ultimate resolution limit becomes a function of the effective beam diameter. Resolution is also affected by the electro-optics and related aberrations, optical image quality, power supply, ripple, detection induced noise and the video signal-to-noise ratio.

If the scanning beam diameter is infinitely small, the ultimate resolution is determined by the video bandwidth. The bandwidth is the upper frequency of the video amplifier used to amplify the signal and depends upon the velocity of the scanning beam. The resolution along the axis perpendicular to the scan lines is determined by the number of scan lines per unit distance.

Almost all electro-optical cameras suffer from image distortions, caused by imperfect electro-optics and electron velocity variations. This is manifested by the lack of geometrical fidelity in the output image. General forms of distortion include, pin cushion, trapezoidal, stretch or compression and barrel (Figure 3.15). These distortions normally occur in combination. In a high quality system, distortion does not vary, thus it can be calibrated using a test chart. When there is a variation between uniformly

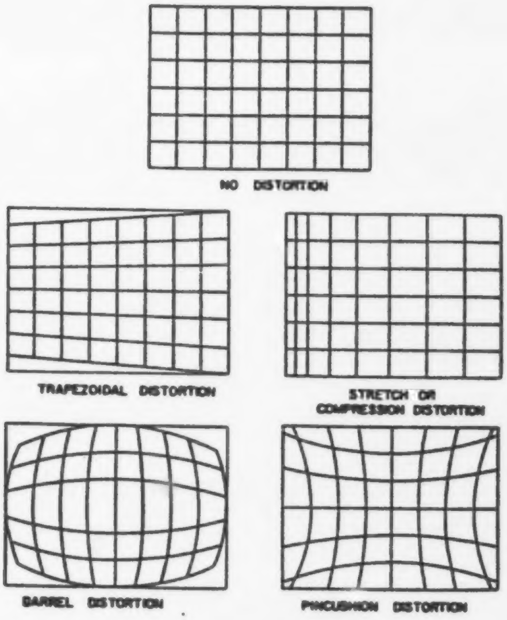

NO DISTORTION
TRAPEZOIDAL DISTORTION
STRETCH OR COMPRESSION DISTORTION
BARREL DISTORTION
PINCUSHION DISTORTION

FIGURE 3.15 FORMS OF IMAGING SYSTEMS GEOMETRICAL DISTORTIONS

illuminated input image and the video output, the effect is called shading. Shading can be corrected with electronic video processing (image enhancement systems).

The ability of a camera tube to reproduce images from moving targets, without smear or blur is a function of illumination, sensitivity, dynamic range, and response time of the system. Smearing or blurring is an indication of lag. Image lag is probably the most important test of camera-tube image quality. Lag can cause a target to be missed in a detection system.

Camera tubes are available with spectral responses ranging from 0.12 to 1.8 μm and can be extended to 14.0 μm if the detectors are cooled. The amount of video signal produced for a given input energy level is called the tube sensitivity. Some tubes can produce usable images under bright light conditions, and others only under low light conditions. For some models automatic sensitivity adjustments are available. Almost all modern camera tubes have a dark current, which is a signal current present when there is no illumination. This varies as a function of tube temperature, but can be compensated for by a reference clamping.

The dynamic range is the range of illumination levels over which a given camera system can produce usable images. Tubes with different ranges are available and in some cases may be adjustable. The slope of the transfer characteristic curve (gamma) indicates the resulting contrast.

If the gamma is too high, there may be a loss in illumination dynamic range; if it is too low, there may be a loss in low contrast detail. A high or low gamma may be desirable for specific applications, but in many instances, a compromise is necessary.

The Vidicon tube is widely used in many applications. It uses a photoconductor material on a glass or quartz face-plate; deflection and focus is achieved by magnetic, electrostatic or a combination of these methods.

The Vidicon is simple and rugged, but due to a lack of gain, is restricted in use to relatively high levels of illumination. It is relatively inexpensive, has a long life and does not require critical adjustment.

Improvements to the basic Vidicon have resulted in modified systems. Notable among these are the Return Beam Vidicon (RBV), silicon diode array, and silicon intensifier camera tubes.

In the RBV, the signal is not derived from the current which flows into the photoconductor to recharge it, but from the depleted electron beam which is reflected from the target. This reflected beam is made incident on the first stage of an electron multiplier, providing a high gain factor. In addition to the higher gain factor, the RBV provides higher resolution than the original vidicon.

The silicon diode array camera tube is essentially a vidicon. However, it uses an array of discrete silicon photo diodes for the photosensitive target, from which the video signal is extracted.

The silicon intensifier camera tube uses a silicon target with a photo-electron input instead of a photon input; an image intensifier is also added. The intensifier generates high-energy photo-electrons from a photo cathode. The silicon intensifier camera tube is a very high sensitivity device that exhibits complete freedom from burning or damage from over illumination.

Image intensifiers are essentially light amplifiers; they are not electro-optical cameras and they do not yield electrical output signals. They are included here because of their application to low light level television (LLLTV) systems.

Each intensifier has a photo cathode of the photoemissive type that emits photo-electrons when light is focused on it. The number of photo-electrons is proportional to the incident radiance. Image forming electrons are electrostatically accelerated before being focused by an electron lens on a fluorescent phosphor screen. The screen is coupled to a camera tube via fiber optics.

Image intensifiers are combined with vidicon or image orthicon tubes to provide an electro-optical imaging capability at light levels much lower than would otherwise be possible.

Gains of a magnitude of 60 are typical for a single stage of intensification. It is customary to cascade several intensification stages in a single device to yield overall gains in the range of 30,000 to 100,000.

Low Light Level Television systems are similar to regular television systems, but the addition of an image intensifier allows them to be operated under low light levels. An LLLTV system can operate under twilight conditions but not in total darkness. This system utilizes starlight, moonlight or sky glow illumination. LLLTV is not confined to low light levels, it will also operate under daytime light levels but is a weather dependent system.

The LLLTV system is an aid to the eye, it expands the spectral region in which the operator can "see". The spectral response region to which it is sensitive ranges from 250 nm to 1.2 µm. Different image tubes will use varying portions of the electromagnetic spectrum. The features of LLLTV that give it outstanding advantages over the eye that is unaided or aided by conventional devices are as follows:

" 1) The objective lens can have light collecting aperture area much greater than the pupil of the eye.
2) The sensitive photo cathode area of the detecting media can be made much greater than its counterpart, the retina of the eye.
3) The quantum yield, or efficiency, of the first detector photo cathode can be substantially higher than that of the retina.
4) The observer's eye can remain light-adapted (photoscopic vision) in viewing the bright picture on the display screen. The resolution of the eye thus remains high and no waiting period for dark adaptation (scotopi vision) is needed.

> 5) The remote viewing system gives more field flexibility and adaptability."
>
> (Gildea, 1970).

LLLTV offers a real-time high contrast, dynamic view of the surface. With slight modifications it can also offer a 360° field of view as well as being pointable. The data is displayed on the screen for real-time viewing but is also recorded on video tape for later reference.

LLLTV systems have been recommended by CCRS as "highly cost effective additions to any oil spill detection package." (O'Neil et al, 1981).

There are a number of applications of remote sensing that can utilize image tube devices. In many cases, an electro-optical device cannot replace a camera or a mechanical scanner, but often it can be used on its own or as a support device.

Table 3.12 gives specifications for common electro-optical systems that are applicable to the sensing of oil slicks. Specifications are also given for real-time displays and video recording. These systems can be used as real-time sensors, search devices, or navigation aids. They can be used stand-alone, as auxiliary or support sensors or as components in more sophisticated sensor systems. As a sensor, they are particularly useful in the detection and monitoring of oil spills when the spectral range is extended to ultraviolet wavelengths, and when used in the LLLTV mode for nighttime and low light applications. Colour cameras

TABLE 3.12 GENERIC TYPES OF CAMERA TUBES

	SIZE	FORMAT SIZE	RESOLUTION	LENS	LIGHT SENSITIVITY (FC)	SPECTRAL RESPONSE	RECORDING MEDIUM	WEIGHT	POWER	POLARIZATION
Vidicon Camera	80x60x154 (mm)	9.5x12.8 (mm)	500 lens at center (horizontal)	8 to 50 (mm)	1 (minimum)	350-850 (nm)	Magnetic tape	.58 to 1.5 kg	3.6 Watts	
LLLTV (typical)		9.5x12.8 (mm)	13 to 30 (L/mm)	12.5 mm (auto iris)	Starlight to full sun	350-850 (nm)	Magnetic tape	69 kg	26 Watts	
TeleMation R181-TM CCTV Camera System	380x100mm		Horizontal center: 450 lines min.	9 mm f/1.4	9 foot candles		Black & White Monitor	(total) 28.5 lbs	12.5 VDC	
RCA TC 103 H LLLTV				Fujinon TV LH 15A2 f/1.4, 12.5 (mm)		350-850 (nm) full width	IVC Model 815XA Video tape recorder (1" tape)	69 kg	110V 60 Hz 4.2A	Polaroid HNP's Horizontal (240-740)
RBV Camera (typical)	80x60x154 (mm)	22.8x22.8 (mm)	70 L/mm	8 to 50 mm (or fixed auto iris)	0.05 (minimum)	350-850 (nm)	Magnetic tape	225 kg	60 Watts	
AOSS LLLTV (UV)				f/1.4	S/N=7 for Visual (quarter moon)	0.32-0.40 (um)	B&W TV Monitor			FOV=15° Horizontal & vertical (across spectrum)
AOSS LLLTV (visible)				f/5.6, f/4.5	S/N=7 for UV quarter moon	.40 to .80 (um)	B&W TV Monitor			FOV=8° & 26° Horizontal & Vertical (across spectrum)
IET Inc. Model SL-1983 81T-LLLTV	15x11x32 (cm)		H=700 L/center 600 L/corners V=350 L/min		$1x10^{-4}$ foot-candles	3,500-8,300 Å	Television Display	10 lbs 4.5 kg	100-135/200-270 VAC 50/60 Hz, 21 Watts 25 VA	Horizontal and vertical
Marconi Avionics LLLTV V0084		FOV 2.66°x2.00° (46.5 mrad x 35 mrad)	440-490 lines in center	16 mm Intensifier Ebsicon	Bright sunlight to starlight		Television Display	42.5 kg (total)	100-125/200-250V, 40-400 Hz, 70 VA	Horizontal and vertical
Marconi Avionics Lowlight Day Modular TV V3341-V3344			Typical 500 lines/picture height	276 mm or 25-500 mm	Daylight or lowlight		Video Recording		100-125V 200-250V 50/60 Hz	

show some promise, but colour calibration and reproduction can sometimes be a problem.

Compared with other sensing systems, image tube devices present advantages and disadvantages.

Advantages

1. Data is available in real time for viewing and/or analysis.
2. Data can be reproduced rapidly and inexpensively.
3. Systems have a wider dynamic range than pure photographic systems.
4. System components are relatively small and lightweight.
5. Systems are inexpensive.
6. Auto exposure control assures acceptable data under variable light conditions.
7. Operation is simple and requires a minimum of training.
8. Most cameras (except when auto iris controls are used) will accept standard "C mount" camera lenses.
9. Detectors respond to filtering for spectral band documentation.
10. Power requirements are low.
11. RBV cameras may be used under low light conditions; LLLTV's under very low light conditions.

Disadvantages

1. Spatial resolution is low compared to photographic systems.
2. Atmospheric conditions limit use, as for photographic systems.
3. The length of the spectral region sensed is limited.
4. Recorded data may be easily destroyed in magnetic fields.
5. Hard copy (photographs) of data may be unacceptable as evidence in court, due to the ease with which data can be altered during production.

3.1.2.4 Forward Looking Infrared (FLIR) Devices

Forward looking infrared devices have been used by the military for reconnaissance purposes for many years. These systems have recently been de-classified and are now available commercially. The simpler systems produced, are essentially small infrared line scanners which may be mounted directly in an aircraft or in a maneuverable pod attached to the exterior of an aircraft or other platform.

The central component of a basic system is the scanner which consists of a mechanical raster scanner, a detector array and an electronics package. Systems are built to operate within the standard infrared region. Fields of view generally do not exceed 30° x 40° and many systems are capable of changing to smaller fields of view.

The mechanical scanning of the field of view is accomplished with a standard raster at normal field/frame rates. Several scan techniques are used. Contiguous scanning is produced by combining high-speed horizontal scanning with oscillating vertical scanning. No calibration sources are provided and therefore, qualitative rather than quantitative evaluation is possible by visually comparing densities within the scene to a ten-step grey scale.

The detector arrays are cooled using liquid nitrogen and are operated at 77°K. A glass dewar is used with the cryogenic system. Different size dewars, and different methods of cooling can be used, depending upon the particular application. Systems have been used with Joule-Thompson cryostat, either open or closed cycle, direct contact cooling with a liquid supply cooler or an expansion-engine mechanical refrigerator.

A standard television display unit is the output viewing device. Video tape recorders and/or data links can be incorporated into the system, depending upon the particular application.

The detectors used in these systems are normally 2 milliradians, although this can be changed depending upon the requirements of the system. The thermal resolution achieved is of the order of 0.2 to 0.4°C.

Better performance can be achieved by utilizing narrow field of view optics with higher spatial resolution.

Normally this does not result in loss of thermal sensitivity. Aperture sizes are available up to 9 inches in diameter, and thus, recognition of small targets at ranges of several miles is possible.

The recognition range capability is a function of target size, clarity of the atmosphere, temperature differential of the target relative to the background; size and resolution of the optics. The limiting resolution and aperture size are closely related. In a well designed system the limiting factor in resolution becomes the instantaneous field of view (IFOV), provided the aperture is sufficiently large. The product of the aperture diameter, d (inches), and the IFOV (milliradians) is best when it is in the range of 0.7 to 1.0. Values larger than 1.0 result in significant degradation of resolution and thermal sensitivity. Figures 3.16 and 3.17 relate recognition range to target size and aperture, for a high contrast target ($T = 8^{o}C$). If T decreases, there will be a decrease in recognition range as shown in Figure 3.18. Changes in temperature of $10^{o}C$ or more produce very little change in recognition or detection range.

Optical trade-offs can be made when specifying system changes. Figure 3.19 shows the relationship between recognition range and optical aperture. This shows that for a longer range of operation, a larger aperture is necessary.

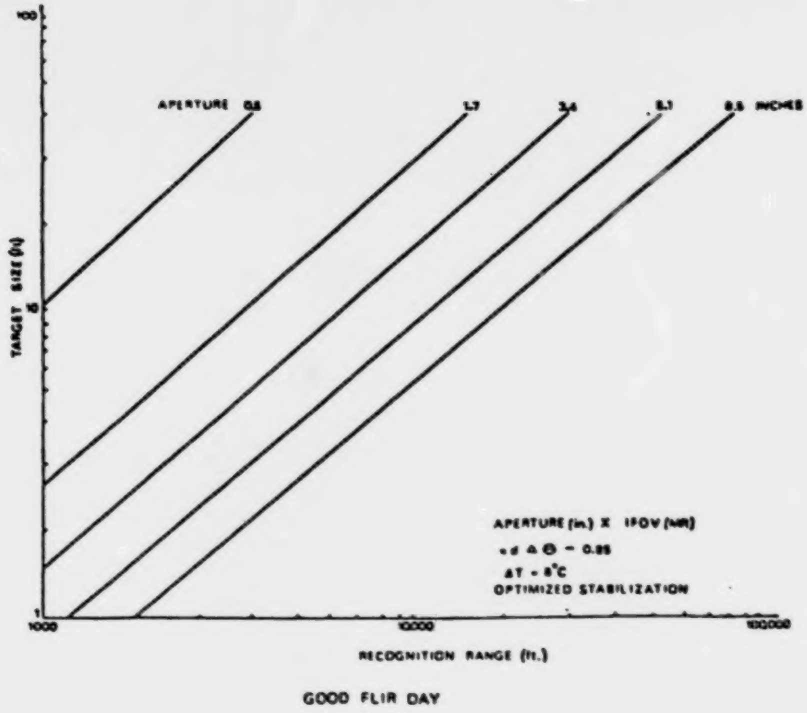


FIGURE 3.16 MAXIMUM RECOGNITION RANGE VS. TARGET SIZE, GOOD FLIR DAY

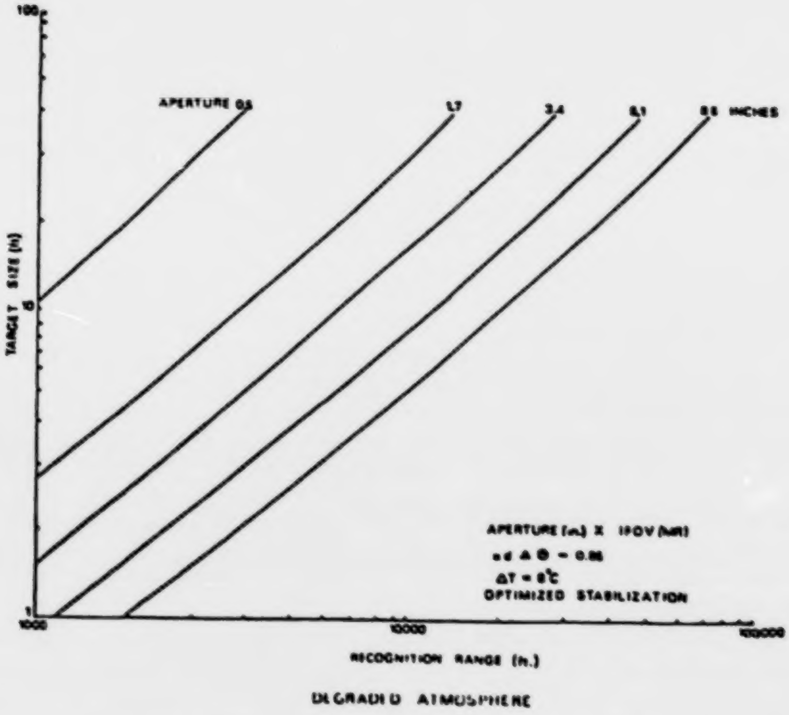


FIGURE 3.17 MAXIMUM RECOGNITION RANGE VS. TARGET SIZE, DEGRADED ATMOSPHERE

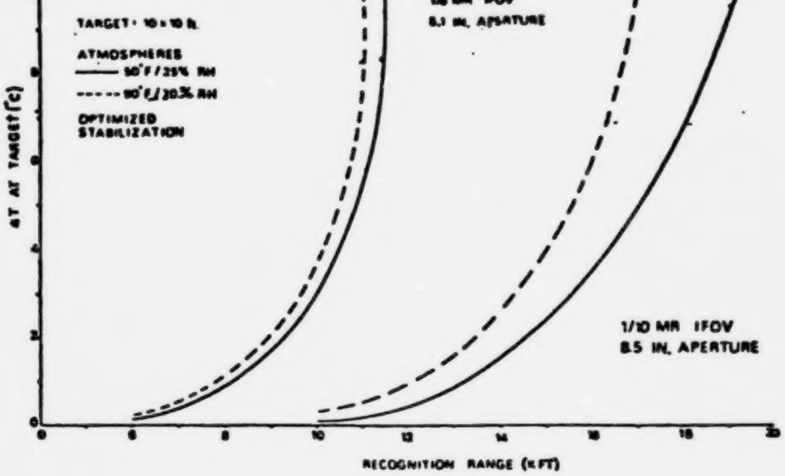
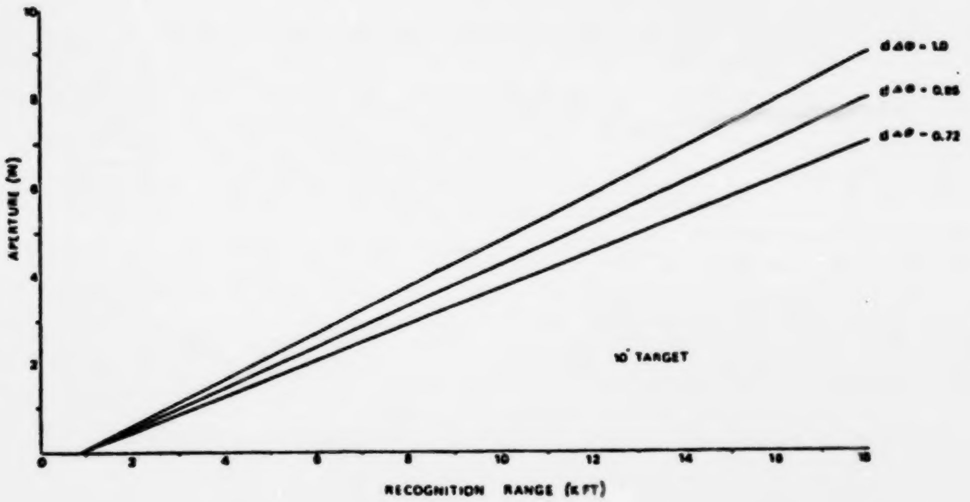


FIGURE 3.18 RECOGNITION RANGE VS. ΔT



GOOD FLIR DAY
OPTIMIZED STABILIZATION

FIGURE 3.19 RECOGNITION RANGE VS. APERTURE

A very similar system to FLIR, but marketed as a thermal television, is available. This is the familiar system used in medicine, heat loss studies and industrial applications. The system is available in single and dual channels and has a calibrated temperature source for quantitative measurement. It is ideal for both laboratory and field testing, and for operational specification development. It is a ground based sensor and consists of six basic components:

1) scanner
2) monitor
3) photo package
4) analogue package
5) digital package
6) ancillary equipment.

The system can be customized, depending upon the application requirement.

The dual channel system is especially useful for infrared target signature analysis, allowing a variable field of view in each channel, high thermal sensitivity in both channels, independent filter and aperture settings; simultaneous viewing and recording of both channels.

There are other forward looking infrared devices that make use of pyroelectric vidicons for thermal imaging. Advances in pyroelectric vidicon technology allow the acquisition of thermal imagery in both stationary and pan modes. The stationary mode of operation requires a chopper, while the pan mode is basically a starring operation. In both cases a moving element is introduced to change the detector view. This refreshes the detector face and allows the registration of a new set of signals. This is important in pyroelectric vidicons as, over a short period of time, if there are no thermal changes in a scene, the data averages out and disappears.

FLIR devices offer excellent possibilities in ground based remote sensing. Table 3.13 gives examples of some types of devices that have been on the market.

3.1.3 Laser Sensors

Active sensors operating at ultraviolet, visible, and infrared wavelengths employ lasers as collimated and monochromatic sources of high energy. The term laser is an acronym for "Light Amplification by Stimulated Emitted Radiation". Lasers as they relate to oil spill sensing are basically of two types - ranging and fluorosensing.

Conventional laser-ranging fluorosensing systems extract information from the phase delay at the modulation frequency between the light emitted and received. Systems which only reflect energy back from the surface, are profilers that measure surface roughness.

An example of a profiling laser is a continuous wave (CW) helium-neon laser centred at 0.6328 μm. It is an amplitude modulated system that captures light reflected back from the surface, using a collecting telescope. The signal

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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is proportional to the light transit time and is a measure of the range. A profiler provides a continuous measure of the variation in terrain or ocean surface heights. Systems are currently available which have footprints of two metres in diameter that are basically independent of altitude.

If a higher power system is used, the vertical transmitted pulse can be used to measure water depth. This is called a laser bathymeter. It measures the time delay between the pulse reflected from the water surface and the pulse reflected from the ocean floor. The difference gives water depth information. The ability of the system to measure depth depends on several unpredictable factors which affect water clarity and bottom reflectivity. These factors vary along a given coastline, and there are limits to the capability of the system to penetrate water. Such a system is basically for shallow water measurements up to approximately 100 m. A large single pulse dynamic range system operating in the blue-green spectral region (about 0.532 μm) has been developed. This type of laser ensures optimum water depth penetration.

Due to the capability of sub-surface sensing, laser bathymeters have some potential for detecting pollutant materials such as tar balls and heavy crudes (specific gravity greater than 1.0) which occur below the water surface.

The other laser potentially suitable for sensing chronic discharge is the fluorosensor. In this system the laser beam illuminates a small area on the surface; any fluorescence induced by the absorption of laser energy is detected and anlayzed by the receiver (commonly a telescopic device). Both pulsed and continuous-wave lasers have been built using nitrogen lasers (0.337 μm), neodynum YAG lasers (0.266 and 0.532 μm), flash-pumped dye lasers (400 and 500 μm) and helium-cadmium lasers (442 μm). A dual-channel spectrograph is usually used to obtain receiver spectral resolution. In the 0.350 to 0.700 μm range, spectral resolution of about 0.2 μm has been obtained. A microprocessor based data acquisition system is used to control the display and store the data.

In more detail, fluorescence occurs when a molecule absorbs a photon and subsequently emits another photon of less energy. The larger wavelength light (lower energy photon) is known as the fluorescence radiation. The optimum wavelength for absorption of light by the molecule, and the wavelengths of subsequent emissions, are determined by the molecular structure. Fluorosensors measure the presence of oil, not the effect of the oil on the substrate, and hence is unhampered by variable backgrounds.

Some thought has been put into the development of an imaging laser system (Waksberg, Sizgoric and Bennett, 1971; O'Neil, Neville and Thomson, 1981). Such a system would operate much like an infrared line scanner. The laser beam would produce an illuminated ground strip. Other researchers have considered the laser working in the same way as a side looking airborne radar.

Table 3.14 gives a listing of many of the developmental prototype laser fluorosensors. No production models exist, and as can be seen from the diversity of laser systems, it appears that no decision on an ideal system has been made. O'Neil, Neville and Thomson (1981) have recommended the use of an eximer laser (0.22 to 0.308 μm) and the development of an imaging laser. The use of the shorter wavelength would improve the sensitivity tenfold (Rayner and O'Neil, 1979) and permit discrimination of oil types in the .300 to .400 μm range.

It should be also be noted that, all the lasers listed in Table 3.14 were originally ground-based prototypes before they were placed on aircraft for airborne sensing applications.

3.1.4 Combined Sensors

Sensors may be utilized in combination for a particular sensing reason.

Active gated televisions are a recent sensor development that are an excellent example of a combined sensor system. They utilize a passive low light level television system coupled with a laser. In the passive mode this sensor functions as an LLLTV with a standard field of view. As with other LLLTV's, various stages of intensifiers are used to increase night time sensitivity. In the active mode, a pulsed laser is used. The pulse is transmitted, a period

TABLE 3.14 EXAMPLES OF SOME LASER DEVICES

ORGANIZATION (TESTING)	TYPE	TRANSMITTER						RECEIVER					RECORDING MEDIUM	WEIGHT (kg)	POWER
		LASER	WAVELENGTH	PULSE LENGTH	PULSE ENERGY	BEAM DIVERGENCE	REPETITION RATE	TELESCOPE	CLEAR APERTURE	FOV	INTENSIFIER ON-GATE PERIOD	SPECTRAL RANGE (nm)			
CCRS MK III	Laser Fluorosensor	Nitrogen gas	337 nm	3 ns (FWHM)	1mJ/pulse	3mrad x 1mrad	100 Hz	f/3.1 Dall-Kirkham	.0232 m^2	3mrad x 1mrad	70 ns	377-689	Computer compatible tape (CCT)	267	28VDC,20.5A 110V, 50Hz, 9A
U.S. Dept. of Navy	1.06 micron CW laser radar system	CW ND; YAG	1.06 micron		Modulated output power 0.2 to 1 watt	9mrad		Reflective Cassegrain	30.5 sq cm	4-24mrad	CW		Magnetic tape		
Spectra physics model 164	underwater LIDAR	argon-ion	488 nm	10 nanoseconds	Peak power up to 75 watts		10^7 Hz	Newtonian	diameter of telescope 20 cm			450-520			
Avco Everett Research Lab.	Raman system	Flash lamp pumped dye	4800 Å	10 ns	Peak power 10^6 watts				aperture diameter 0.3 m	10mrad					
AVCO C-950	Fluorosensor	Nitrogen/neon	3371.1Å 5400.6Å	9 ns (FWHM) 3 ns (FWHM)	Peak power 140 kw 20 kw	13.9mrad x 3.6mrad	1 to 100 pps (continuously variable) or single shot	Newtonian	diameter 20.3 cm				Magnetic tape		
Environment Canada	Fluorometer	Helium Cadmium	442 nm & 325 nm			1mrad		Schmitt Cassegrain			CW			100	60 Hz, 120VAC
NASA & Sparcom Inc.	Fluorosensor	Nitrogen	337 nm	10 nsec	1mJ/pulse	30 x 2mrad	100 pulses per sec	f/1 Cassegranian	diameter 28 cm			450-500 nm 540 for bathymetry	Magnetic tape		
NASA	Laser Bathymeter	Neon frequency doubled Nd:YAG	540 nm 532 nm	5 to 7 nsec	Peak power 2 kw 12 mJ 2 Mw 10 mJ	2 x 5mrad	10-200 pps 10- 50 pps	f/1 Cassegranian	diameter 28 cm				Movie camera or magnetic tape	90	

of time proportional to target range distance is waited, then the camera intensifier is "gated on" to act as a receiver. In this mode the field of view of the LLLTV is reduced due to the range measurement of the laser. However, targets still fill the full screen, and the sensitivity of the LLLTV is utilized to increase data acquisition. This system is presently used by the United States Coast Guard for vessel identification at night (White et al, 1979).

The active gated television system (AGTV) was developed by the USCG for use in the AIREYE sensor package (White et al, 1979). The main purpose of the AGTV was to identify violators polluting water with oil under cover of darkness. Other uses envisioned were: vessel traffic management, fisheries patrols, search and rescue, etc. Because of its unique capabilities in remote sensing of oil spills, a detailed outline of this sensor system is presented.

The AGTV sensor can be operated either in a passive or active mode. In the passive mode, it will function as an LLLTV and have a maximum field of view of 18°. It is capable of detecting deck lights of 320 candella at a range of 21 km. As the aircraft approaches the ship, the field of view is automatically reduced to 6.5°, and finally to 2.3°. At a slant range of 4 km, the AGTV is switched to the active mode, and small ships (6 x 18 m) can be observed.

In the active mode, illumination is provided by a one watt, pulsed, lead-vapour laser. After the laser is pulsed, the camera waits a period of time proportional to the range on the target, and the camera intensifier is "gated on" to the reflected light from the target. At a slant range of 500 m, 30 cm high letters can be resolved and 15 cm high letters are readable at 300 m.

Other combined systems are used by the military. They consist normally of LLLTV, FLIR and a laser range finder. The outputs are manually correlated by a system operator, although digital signal processing packages are available for data integration. These systems are used for reconnaissance, search and rescue and other military purposes.

3.1.5 Fraunhaufer Line Discriminator

A level of success has been achieved with an instrument called a Fraunhaufer Line Discriminator. It measures luminescence to detect sources of pollution. The instrument uses the sun as an excitation source and permits detection of luminescent materials during daylight hours.

The basic principle of the system is to measure the Fraunhaufer dark lines in the solar spectrum. The dark lines are caused by selected absorption of light by gases in the relatively cool upper part of the solar atmosphere. The sharpest and deepest lines occur in the ultraviolet, visible and near infrared regions of the spectrum.

The method of measurement involves the observation of a selected Fraunhaufer line in the solar spectrum. The ratio of the control intensity of the line to a convenient point on the continuum, a few tenths of nanometers distant, is measured. This ratio corresponds to a measurement of the amount of luminescence.

The basic system consists of an optical head, an electronic console and a light collector. The optical head consists of two telescopes, one that looks skyward and the other looks earthward. A chopper wheel, filters and a photomultiplier complete the optical head. The two sources of light are correlated and fed to a minicomputer that generates luminescence and reflectance values (Watson, Hemphill and Bigelow, 1975).

3.2 Microwave/Radar

3.2.1 Passive Microwave Systems

Passive microwave systems measure the thermal radiation emitted by the target plus the energy from other sources reflected from it. By using the Rayleigh-Jeans approximation to Planck's law in the microwave region, the emitted radiant power (P), from a blackbody in a narrow frequency interval (B), may be characterized by its thermometric temperature (T)P

$$P = \frac{kTB}{\lambda 2} \qquad (3.3)$$

where λ is the wavelength and k is Boltzman's constant. Since most targets are not perfect blackbodies (having an emissivity e, $0 < e < 1$), another term, Brightness Temperature, T_B, is used to describe the target,

$$T_B = eT \qquad (3.4)$$

In a practical situation, a radiometer viewing the surface of the earth measures contributions from surface emission (T_B), emission by the intervening atmosphere, and atmospheric emitted radiation reflected by the surface, in the direction of the radiometer. The temperature equivalent to the energy measured by such a radiometer is termed the apparent temperature. Atmospheric conditions influence the measured apparent temperature through an atmospheric attenuation coefficient, which represents oxygen and water vapour absorption. Under clear sky conditions, and operating at frequencies in the window of the absorption spectrum, the atmospheric effects can be reduced considerably. Usually, if meteorological information is available, the atmospheric attenuation can be calculated or measured directly.

The brightness temperature and associated value of emissivity in equation 3.4 is a function of polarization of the measured radiation (horizontal or vertical polarization) and look direction, or angle at which the surface is viewed. The emissivity of the surface is related to the scattering behaviour of that surface integrated over half-space. Two types of surface models are generally used for relating emissivity and reflectivity; specular and very rough surfaces. For relatively smooth surfaces (in terms of wavelength) a specular model is used, in which case $e = 1-p$, where p is the reflection coefficient. For a very rough surface, the Lambert Surface may be used. This characterizes e in terms of an average differential scattering coefficient, Y_o, with

$e = 1 = y_o/4$. A Lambert Surface is insensitive to both polarization and incidence angle. As most natural surfaces exhibit a character somewhere between the two limiting cases, an empirical approach is normally used to determine emissivity. The emissivity is related to the surface reflection coefficient, which in turn is related to the dielectric properties of the surface.

Some of the major characteristics of microwave radiometers are, that the input signal is incoherent and, the system operates with long integration times. The longer a radiometer views a target the better is its sensitivity. The most commonly used radiometer receiver is the Dickey radiometer, which measures the signal level relative to a reference. The sensitivity of a typical radiometer is $1^{\circ}K$.

Microwave radiometers can be ground-based, monitoring the atmosphere for meteorology and pollution, or they can be made to look at the earth or ocean from raised antenna platforms. To make measurements around this platform, the antenna has to be mechanically scanned in azimuth and elevation.

Airborne microwave radiometers are being used in both profiling and imaging modes. In the profiling mode a narrow-beam antenna is pointed in a fixed direction and the motion of the vehicle is used to produce measurements along the flight line similar to other profiling systems.

Microwave radiometric imaging is produced by scanning a narrow beam antenna in the cross-track direction and utilizing the vehicle motion to produce scanning images (Figure 3.20). The signal obtained for each across-track scan is used to modulate a single line of a CRT which is in turn used to expose the film. The film is moved proportional to aircraft speed. The spatial resolution in both profiling and imaging systems is achieved by the angular beamwidth of the antenna (Figure 3.21). The absolute resolution at range R, is given by Rb, where b is the antenna beamwidth in radians. The resolution cell size is thus increased with increasing range.

Microwave radiometers have been used from surface-based, airborne and space-borne platforms for ice mapping, oil pollution detection, and ocean surveillance.

3.2.2 Active Microwave Systems

Active microwave systems are called radars. Most radars use frequencies over the range 0.5 GHz to 200 GHz. They provide their own source of electromagnetic waves. Waves are transmitted and then received back from the target. The returning waves undergo changes caused by the target and the environment. Because the characteristics of the radar source can be controlled, and even phase correlation between the transmitted and received signal is possible, a variety of choices are available in designing a radar. Radars are used for many purposes besides detection, and many devices called radars do not measure range. The term radar is commonly used for any device that measures scattering and reflection of electromagnetic waves provided

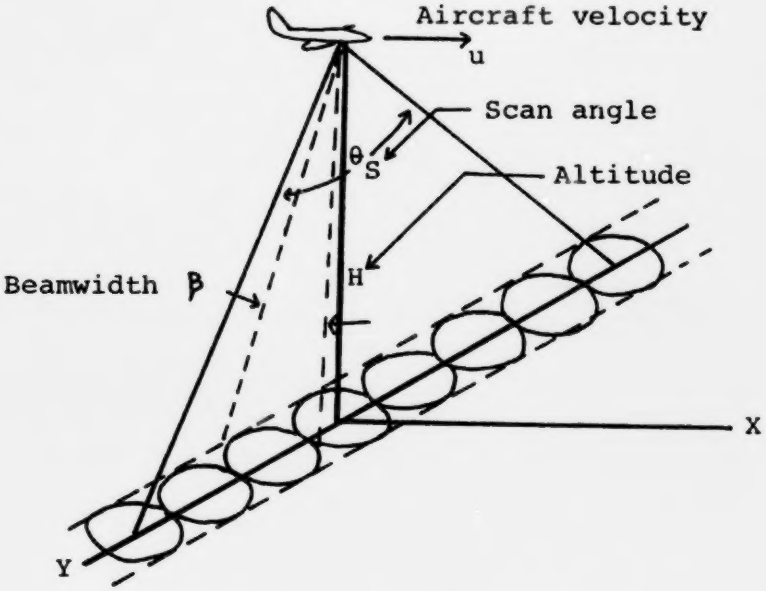

Aircraft velocity
u
Scan angle
θS
Altitude
Beamwidth β
H
X
Y

FIGURE 3.20 GEOMETRY OF AIRBORNE SCANNING MICROWAVE RADIOMETER

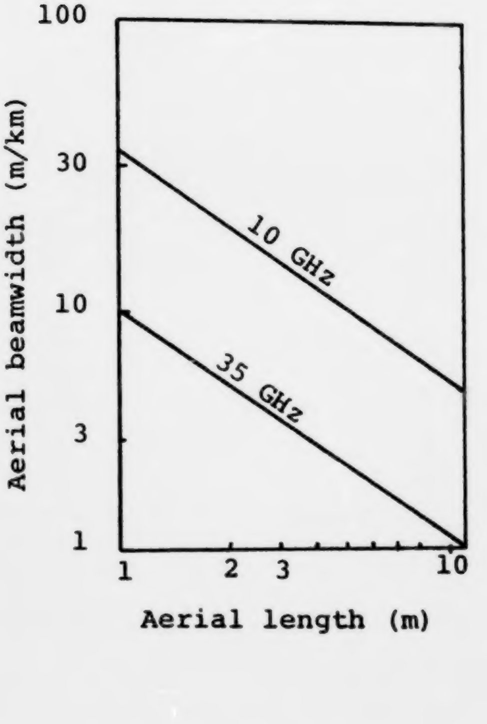


FIGURE 3.21 AERIAL BEAMWIDTH (RESOLUTION) VS. AERIAL LENGTH

by the radar itself.

Radar backscatter is governed by the geometry and dielectric (or conducting) properties of the target. Significant geometric variations and dielectric properties are dependent on wavelength. Thus, physical sizes, as well as the rate of phase change or attenuation, are usually described explicitly in terms of the wavelength. Small sources radiate nearly uniformly in all directions, which means that backscatter for small targets is almost independent of the direction of illumination. The size of the scattering cross-section depends on the amount of "gain" of the target (similar to antenna gain), and whether the main scattered beam is towards the receiver or away from it. Flat surfaces tend to radiate in a specular direction, so that the radar receives only a small portion of the returned energy for normal incidence. Thus, as incidence angles increase, the amount of backscatter is reduced. Rough surfaces, on the other hand, tend to return larger portions of the signal back toward the radar, but send a weaker signal in the specular direction.

The geometry of many radar targets can be approximated by combinations of simple shapes such as cylinders, corner reflectors, spheres, discs, planes, etc. The geometry of relatively large surfaces is sometimes described in terms of facets, or relatively flat, small sections of the surface. Because scatter is greatest for flat surfaces when the energy is normally incident, facets perpendicular to the incoming radiation are the largest contributors to radar backscatter. Surface roughness can also be used as a descriptor for large area targets. However, specifying surface roughness for a target is a problem.

Dielectric properties affect the scattering properties primarily through the effect on the reflection coefficient, and amount of sub-surface penetration. For good conductors, or for dielectric materials having a large permittivity, the size of the reflection coefficient is about unity.

In view of the above, the radar backscattering coefficient of a target is dependent on frequency, angle of observation, and polarization of the transmitted, and received radiation. It is possible to transmit either horizontal (H) or vertical (V) linear polarization and receive the same polarization which is transmitted and/or the cross-polarization. The cross-polarization signals (HV or VH) are generally considered to be due to multiple surface scattering and/or to volume effects. By reciprocity HV and VH signals should be the same.

The utility of a radar, or any other sensor, is often determined by its ability to resolve adjacent objects. For sensing the ground, resolution refers to the ability to discriminate between two objects separated by the "resolution distance". This ability is strongly dependent on the relative amplitude of the returns from the two objects to be resolved, and upon their contrast with respect to the background. In radar terminology a less correct but simpler definition of resolution is often used. The "resolution cell" is defined as the region on the ground contributing to the signal observed at a particular instant, and its boundaries are separated by the "resolution".

Many sensors resolve on the basis of angle: passive microwave radiometers, cameras, and infrared scanners. Radar systems on the other hand, are permitted additional resolution options because range is determined by measuring the time delay, and speed by measuring the Doppler frequency shift.

3.2.2.1 Side Looking Airborne Radar (SLAR)

Side looking airborne radar is a terrain imaging system, which generates images that record the reflective properties of the terrain at microwave frequencies. SLAR is designed to "look" to the side of the aircraft and to transmit a beam in a fixed direction which is usually perpendicular to the line of flight. Along-track coverage of ground features is accomplished by the forward motion of the vehicle carrying the radar, which causes successive transmitted beams to cover new areas. The radar block diagram and the geometry of a SLAR operation is shown in Figure 3.22. Imaging radars like SLAR are not calibrated, in that the transmitted power is not monitored.

SLAR is a non-coherent system and is also known as a real-aperture radar because it achieves resolution in the

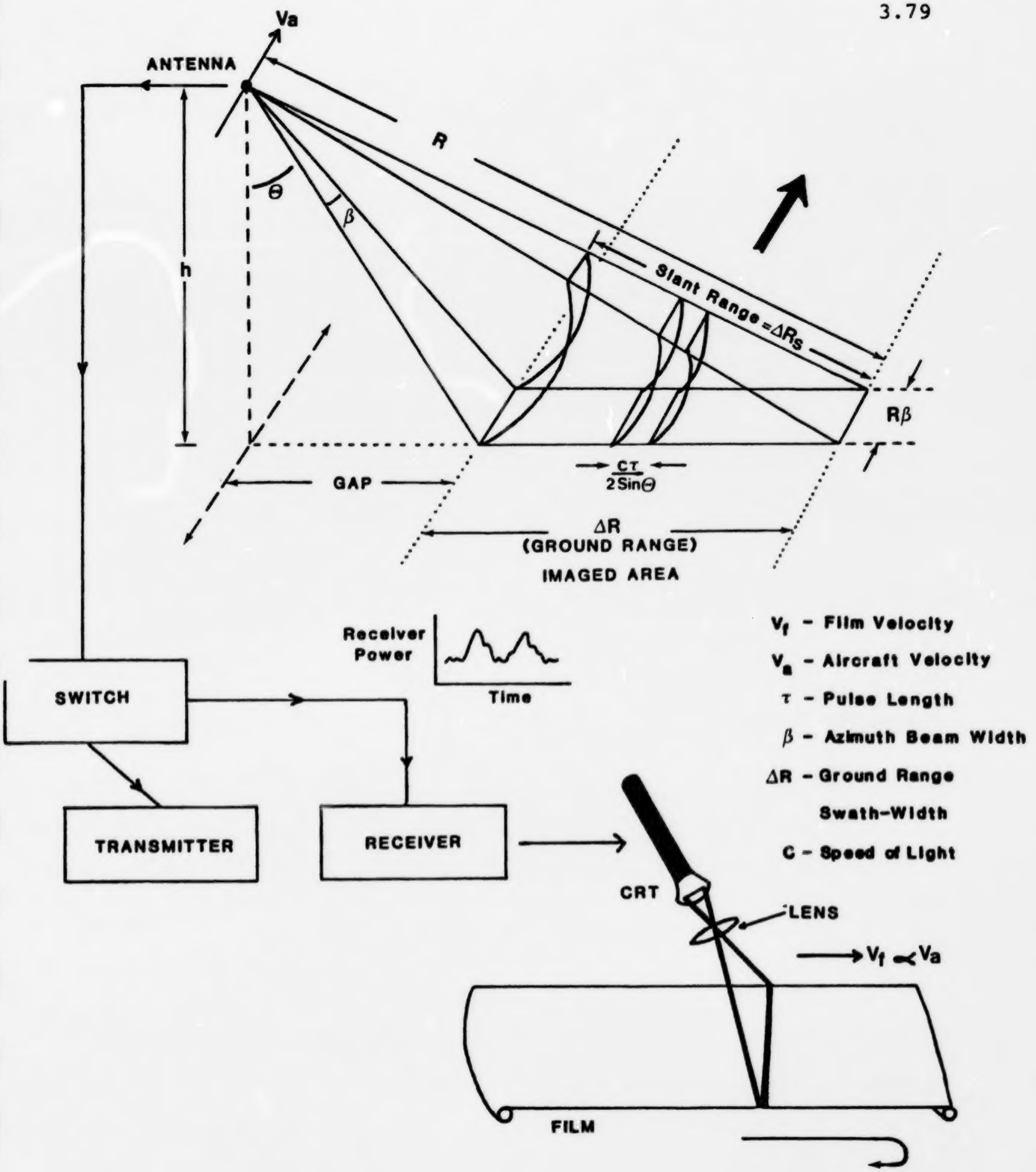

Va
ANTENNA
R
Θ
β
h
Slant Range = ΔRs
Rβ
GAP
cτ / 2 Sin Θ
ΔR
(GROUND RANGE)
IMAGED AREA
Receiver Power
Time
V_f - Film Velocity
V_a - Aircraft Velocity
τ - Pulse Length
β - Azimuth Beam Width
ΔR - Ground Range Swath-Width
C - Speed of Light
SWITCH
TRANSMITTER
RECEIVER
CRT
LENS
V_f ∝ V_a
FILM

FIGURE 3.22 SIDE-LOOKING AIRBORNE RADAR GEOMETRY (REAL APERTURE)

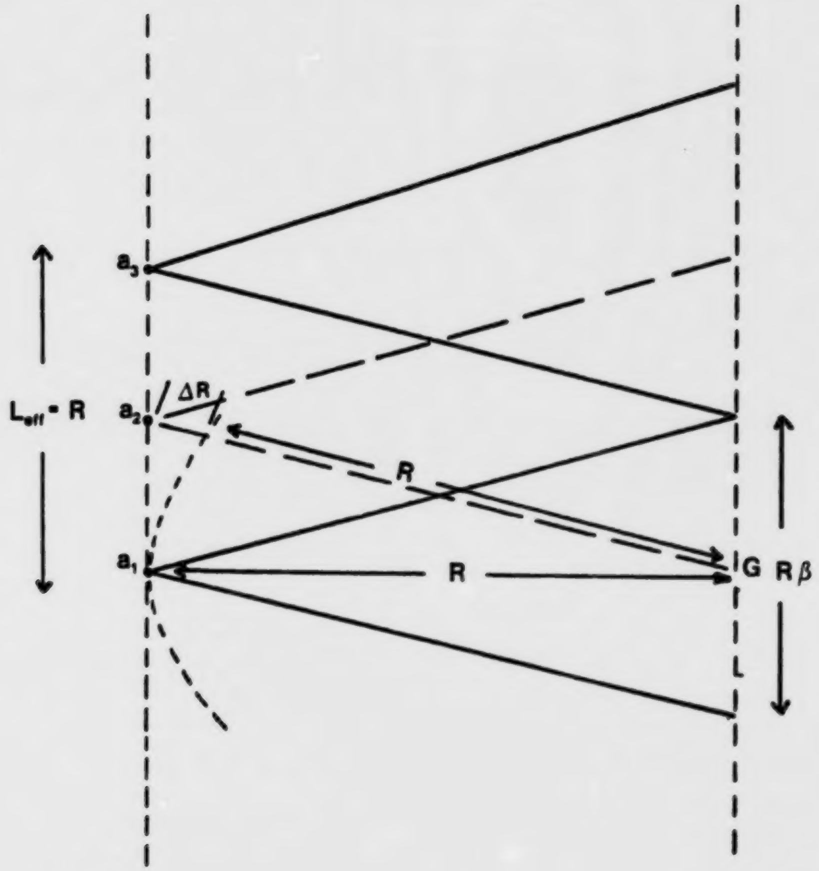
along track direction through the angular beamwidth of the antenna. The term "non-coherent" means that the system records amplitude information only and ignores the phase of the returned signal. A narrow beamwidth provides a smaller resolution cell width. A beamwidth can be narrowed by either increasing the length of the antenna, increasing the frequency, or both. The smallest beamwidth is limited by the physical length of the antenna which can be conveniently accommodated on an aircraft. In addition, the resolution cell size achievable through the beamwidth limited systems is dependent on range increasing with it. Thus, only moderate to poor spatial resolutions are achievable in the along track direction at high aircraft altitudes.

In the across-track or range direction, resolution is dependent on the transmitted pulse length or its bandwidth. Shorter pulse width and higher bandwidth signals provide smaller resolution cells. The total ground coverage in the across-track direction is given by the swath-width. Both a ground-range and a slant-range mode is possible in image presentation. The swath-width is determined by the pulse repetition frequency and the antenna beamwidth in the vertical direction. Usually the pulse repetition frequency (PRF) or the number of pulses transmitted per second is the limiting factor in conjunction with the aircraft speed.

3.2.2.2 Synthetic Aperture Radar (SAR)

The synthetic aperture radar is also a side-looking airborne radar but differs from the real-aperture SLAR in the way it achieves its along track resolution. Real-aperture SLARs achieve along track resolution through the antenna beamwidth, whereas synthetic aperture radar takes advantage of the coherence of the transmitted radar signal, to permit processing of the returns received, as the radar flies past the target. It produces a resolution that requires a much longer antenna than can be realistically carried in an aircraft or spacecraft, using a real-aperture system. Thus, the range/speed measurement technique is realized in SAR systems to achieve a resolution cell size much smaller than that achieved by the angular beamwidth of the antenna.

Figure 3.23 is an illustration of how SAR achieves the along-track resolution. The different positions of the antenna along the flight line are given by a_1, a_2 and a_3. At each of these positions the beam illuminates an along-track distance given by Rb, where b, is the antenna beamwidth and R is the range. Thus, the effective antenna length, L_{eff}, available for the synthetic aperture is equal to Rb. During this distance travelled by the aircraft a particular point on the ground is within the physical antenna beamwidth. The factor of 2 in estimating the effective beamwidth, b_{eff}' from L_{eff}, is due to the round trip phase difference (in transmitting and receiving) rather than the



Beamwidth , $\beta = \dfrac{\lambda \text{ (wavelength)}}{D \text{ (antenna length)}}$

Angular Resolution at Range R , $R\beta = \dfrac{R\,\lambda}{D}$

Length of "Synthetic Aperture" , $L_{eff} = \dfrac{R\,\lambda}{D}$

Beam Width of "Synthetic Aperture" , $\beta_{eff} = \dfrac{\lambda}{2L_{eff}}$

(factor of 2 because of the round-trip phase shift)

Effective Angular Resolution at Range R , $R\beta_{eff} = \dfrac{R\,\lambda}{2L_{eff}} = \dfrac{(R\lambda)D}{2(R\lambda)} = \dfrac{D}{2}$

FIGURE 3.23 ALONG TRACK RESOLUTION FOR SYNTHETIC APERTURE RADAR (SAR)

single trip phase difference used in estimating b. Thus, the effective along track resolution obtained by synthetic aperture techniques for a fully focused case is given by:

$$\text{Resolution (focused)} = D/2 \qquad (3.5)$$

where, D is the physical length of the antenna. If the full effective aperture length, L_{eff}, available for creating the synthetic aperture is not used, then the resolution cell size is increased proportionally. Thus, an along-track resolution independent of range and wavelength, is achieved with SAR techniques.

In obtaining the theoretical resolution, D/2, it is assumed that phase compensations are made for differences in the path lengths from different antenna positions along the flight line to a particular point on the ground. For example, to keep the point, G, in focus at antenna position a_2 in Figure 3.23, phase compensation corresponding to the distance, R, has to be introduced in the obtained signal. If this phase compensation is not undertaken, the system is said to be unfocused, or focused at infinity. When the system is unfocused the resolution obtained is given by:

$$\text{Resolution (unfocused)} = \frac{1}{2} R \qquad (3.6)$$

The synthetic aperture radar system geometry and block diagram are similar to Figure 3.22, except that a "coherent detector" is used. This means that the output must be presented in a way to preserve phase so that later processing can be used to obtain phasor sums from the returns received at different times.

The coherently detected signals may be recorded on any medium having sufficient bandwidth. A common technique uses film recording, similar to that used for the ordinary real-aperture SLAR (Figure 3.22). Since both negative and positive values must be available for phasor addition, the recording level on the CRT is set with zero at an intermediate grey level, permitting black to be used for a strong negative signal and white for a strong positive signal.

The SAR signal recorded on film is a one dimensional hologram, and an image may be made from it by optical techniques similar to those used for hologram construction. An optical system for producing an image from a synthetic aperture signal film is shown in Figure 3.24. Numerous other processing schemes can be implemented for SAR, including recently developed digital techniques.

The degree to which the ideal resolution (D/2) may be approached is dependent on the accuracy with which the position of the aircraft is known. Positional accuracy of up to $\pm \lambda/16$ across the length the synthetic aperture (L_{eff}) is needed. At X-band frequencies (3.2 centimeter wavelength), a flight path accuracy of ± 2mm is required over apertures which may be as much as tens or hundreds of metres in length. This is obtained by employing an inertial platform as a reference and using aerial stabilization.

Radar images, and in particular SAR images, are

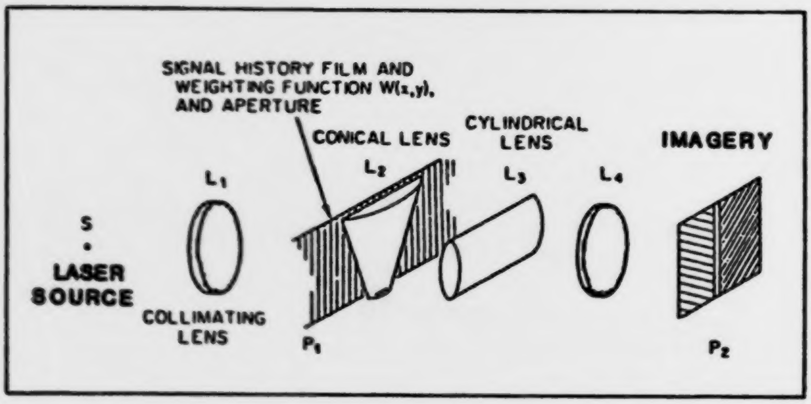

SIGNAL HISTORY FILM AND
WEIGHTING FUNCTION W(x,y),
AND APERTURE
CONICAL LENS
L_2
CYLINDRICAL
LENS
L_3
IMAGERY
L_1
L_4
S
LASER
SOURCE
COLLIMATING
LENS
P_1
P_2

FIGURE 3.24 OPTICAL PROCESSOR FOR SAR SIGNAL FILM USING A CONICAL LENS

speckled in appearance because of fading, or scintillation, resulting from phase interference. Each pulse return is a single sample from a signal which is exponentially distributed. Each distance, D/2 in azimuth and c/2B in range, (c is velocity of light and B is bandwidth) provides one independent sample. Thus, SAR systems achieving the theoretical limits of azimuth resolution (D/2) provide only one independent sample. The speckling may be reduced, and the accuracy of measurement may be improved, by averaging several independent samples having exponential distributions. Thus, averaging over several resolution cells is needed to obtain a reliable estimate of the backscatter coefficient (accurate position on the dynamic range scale: grey tone). A real-aperture SLAR system averages many independent samples inherently because the obtained azimuth resolution (Rb) is much larger than the distance, D/2. Thus, there is a trade-off between resolution and backscatter coefficient accuracy. For many applications, averaging is not as important as resolution, since only the shape and context of the items imaged are important. For automatic spectral recognition and many other applications, good grey scale information is needed and this requires significant averaging.

3.2.2.3 Scatterometers

Scatterometers are radar systems that provide quantitative measurements of backscattering coefficients over a range of incidence angles. These angular measurements allow more knowledge to be obtained about the terrain than can be acquired from the single measurement of the point with an imaging radar. A primary purpose for scatterometers, however, is to provide information regarding the sensitivity and dynamic range required for designing imaging and other radars. The scattering coefficient, σ, as a function of angle, measured by a scatterometer, can also be used to calibrate, interpret, and classify radar imagery. In a scatterometer, the ratio of received to transmitted power is measured, providing an absolute value of the radar scattering coefficient. As a scatterometer is designed to measure the scattering coefficient, it cannot tolerate a large uncertainty in measurement, and requires the averaging of many independent samples. To achieve adequate averaging, the scatterometer normally sacrifices resolution.

Two principal types of airborne scatterometers have been used: the pencil beam system and the along-track fan beam system. With a pencil beam (narrow conical pattern), the antenna is pointed at some incident angle, while the aircraft flies far enough to achieve sufficient averaging. The incidence angle is then changed, and the flight path is repeated. One problem with such a system is, that measurements at different angles correspond to different parts of the terrain.

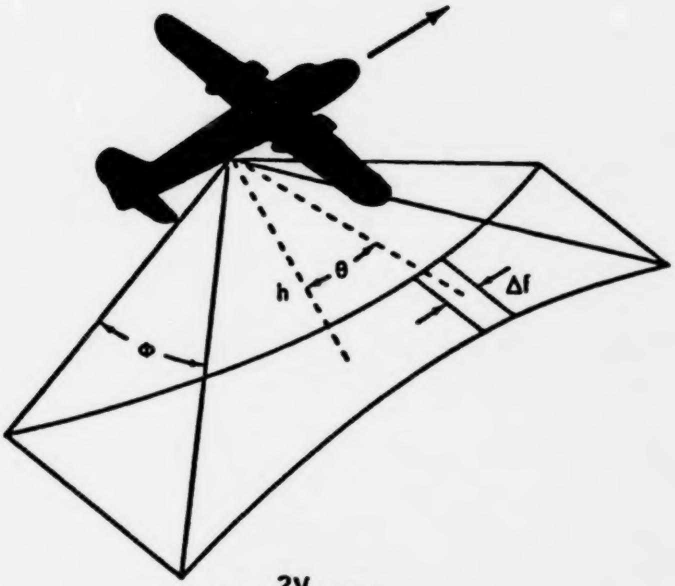
The along-track, fan beam system, makes use of doppler information and has a narrow beamwidth in the across-track (about 3°) and a wide beamwidth (160°) in the along-track (Figure 3.25). Returns may be observed from different parts of the terrain, at different incident angles, simultaneously. The scattering coefficients from different angles are successively collected, and are correlated to obtain a set of scattering coefficient-versus-angle curves for all points or resolution cells beneath the flight track. These curves can be generated for angles fore and aft of the aircraft. Some systems also provide simultaneous polarization combinations (HH, HV, and VH).

In addition to the above, special ground based scatterometers have been developed which provide measurements at a wide range of frequencies at all polarization combinations. The antennas for such systems are usually mounted on a cherry-picker truck or tower. Some special systems have been designed for operation from a helicopter. These systems provide very small resolution cell sizes (1 to 2 metres), thus, require significant averaging of independent samples to obtain an accurate value of the radar backscattering cross-section. Averaging is obtained by taking several independent measurements of the same resolution cell.

3.2.2.4 Marine Radars

Marine radars are used onboard vessels to monitor a 5 to 50 kilometre surrounding zone. The radius of coverage can be lengthened by increasing the antenna height above the ocean surface and by increasing the wavelength.

Marine radars utilize an antenna which has a narrow beam (about 1° to 2°) in azimuth and a wide beamwidth



$$F_d = \frac{2V}{\lambda} \text{ SIN } \theta$$

Where: F_d = Doppler frequency
V = True ground speed
λ = Wavelength
θ = Incidence angle, measured from nadir

Φ = Lateral beam width angle
h = Altitude above terrain
Δf = Doppler resolution, determined by adjustment of spectrum-analyzer filter bandwidth during data reduction

FIGURE 3.25 DOPPLER SCATTEROMETER MEASUREMENT GEOMETRY FOR THE ALONG-TRACK FAN BEAM SYSTEM

(about 15° to 20°) in elevation. The antenna is mechanically rotated to sweep 360° continuously in the horizontal plane. The resolution cell in the horizontal direction is determined by the azimuth beamwidth, and in the range direction by transmitting a short pulse. The power return, corresponding to the pulse length, is displayed on a cathode ray tube (CRT) which is known as a PPI (Plan Position Indicator) display. The centre of the PPI corresponds to the position of the antenna. The radial distance from the centre provides a range to the target in a particular azimuth direction. The display of each return pulse on the PPI is synchronized to the azimuth direction of the antenna. Thus, a 360° azimuth view around the vessel, with a range depicted as increasing distance from the centre, is obtained. A large vertical beamwidth in such systems is used to compensate for the roll and pitch of the vessel.

Due to the small antenna beamwidth and atmospheric attenuation considerations, marine radars utilize X- and S-band frequencies. Three pulse lengths (1, 0.25, 0.05 microseconds) are usually available, with the shortest pulse length used for short range operation (less than 1.5 nautical miles). For a pulse length of 1 microsecond and a beamwidth 1°, a resolution cell size of 150 x 175 m is obtained at a 10 km range.

Shipborne radars have also been used from shore-based installations to continuously monitor sea ice conditions within the radar range. With shore-based radars, a large vertical beamwidth is not necessary, allowing for greater flexibility in designing radars for site-specific shore-based installations.

Special video tape recording systems are available for data storage and subsequent analysis. The PPI display can also be photographed to provide a hard copy of the information.

3.2.2.5 General Comments

Radar records the distance to a reflecting object. This introduces typical distortions in the reflected image when compared with a map of the terrain being surveyed (Figure 3.26). The radar records the distances, OA, OB, OC, etc. and not NA, NB, NC, etc. When distances OA, OB, etc., are displayed the resulting image is called a slant range presentation. However, it is possible to correct this in the system and provide a ground range presentation in which distances NA, NB, etc., (or NB-NA, NC-NA, etc.) are displayed. At low altitudes, or over very large distances (high value or range (R) over height (H):R/H), the corrections are minute and a nearly orthographic image is achieved. As is clear from Figure 3.26, in a slant range presentation mode, distortion is greatest at near ranges.

In addition to the above, two types of parallax (echo and shadow) are encountered in radar imagery. Since radar measures distance, the top of a high object is recorded before the bottom when the aircraft is flown at a certain

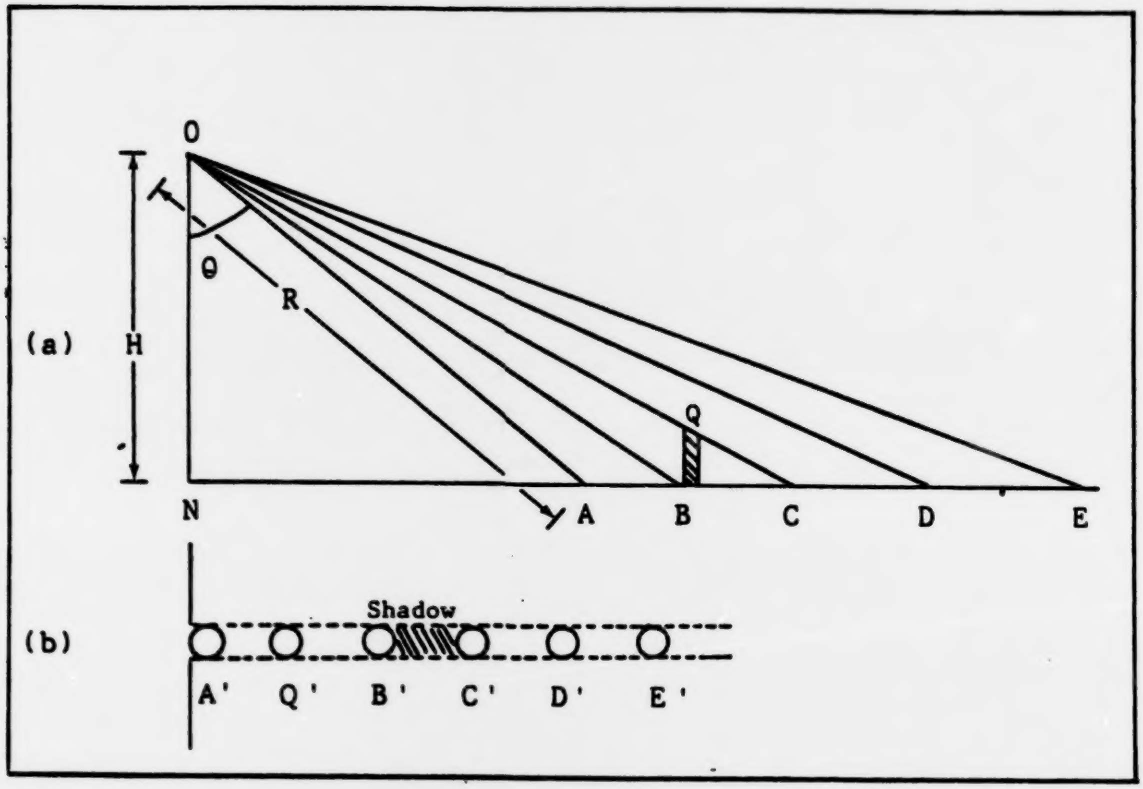

O
θ
R
(a)
H
Q
N
A
B
C
D
E
(b)
Shadow
A'
Q'
B'
C'
D'
E'

FIGURE 3.26 RANGE DISTORTION FOR SLAR IMAGERY

(a) Imaging Geometry. Actual targets at A, B, C, D and E.

(b) Slant Range Presentation. (Recording starts at A and distances (OB-OA), (OC-OA), etc. are registered.)

height. As shown in Figure 3.26, 0Q is less than 0B, therefore Q is recorded before B. This "inverted" echo rapidly decreases in size as the distance between the radar and the target increases (higher values of R/H). Also, for a radar located at 0, the target BQ screens the area between B and C from observation. BC therefore, cannot be recorded (no signal) and shows up in the image as an area without echoes (a black area or "shadow"). This radar shadow can in some cases be used for height measurement providing the viewing geometry is known (Figure 3.27). Radar shadow increases with distance (higher values of R/H). Shadow can also be used to improve image contrast. Small differences in target heights can be enhanced by flying low.

SLAR is a line-scan system, imaging a continuous strip of the earth's surface line by line. This means that to obtain a geometrically correct depiction of the earth's surface, a line by line correction of the image is necessary, taking into account all aircraft movement such as: pitch, roll, yaw, drift, velocity changes and altitude changes. The separate effects of yaw, pitch and cross-track deviations on mapping a square grid are shown in Figure 3.28. Actual distortion in a SLAR image is a composite of these effects.

Each SLAR unit operates at a single frequency. The most popular frequencies for SLAR lie between 6 and 40 GHz (wavelength of 0.5 to 0.8 cm). Table 3.15 shows some para-

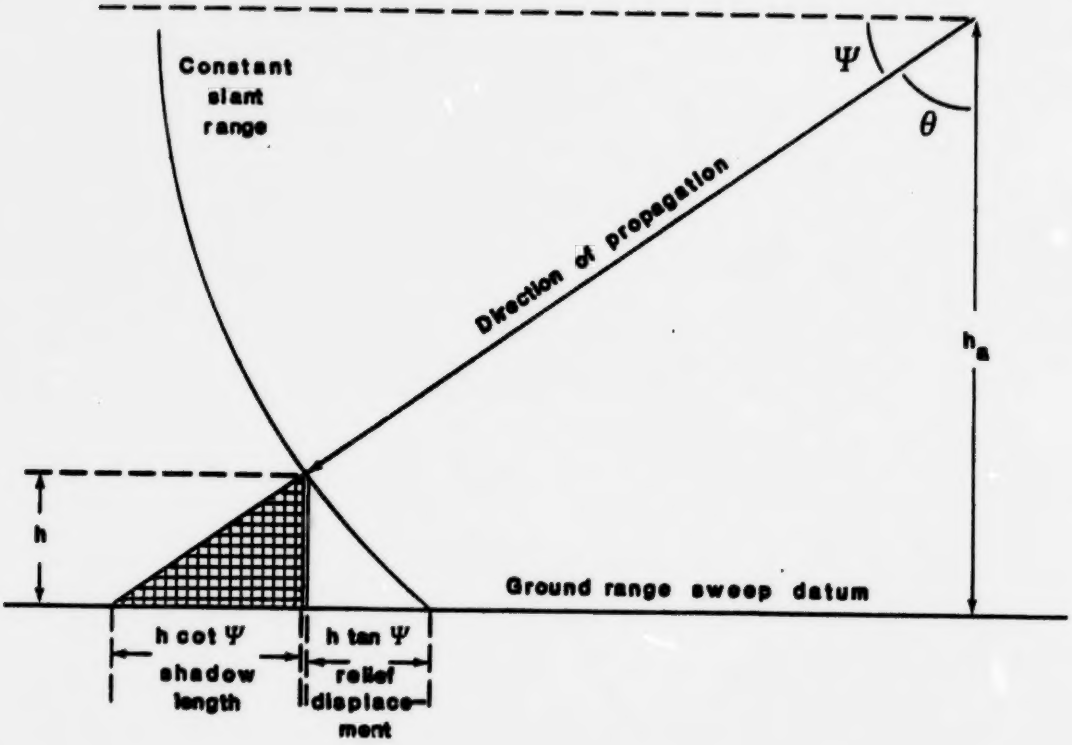

Constant slant range
Ψ
θ
Direction of propagation
h_a
h
Ground range sweep datum
h cot Ψ
shadow length
h tan Ψ
relief displacement

FIGURE 3.27 SLAR SHADOW AND RELIEF DISPLACEMENT (American Society of Photogrammetry, 1975)

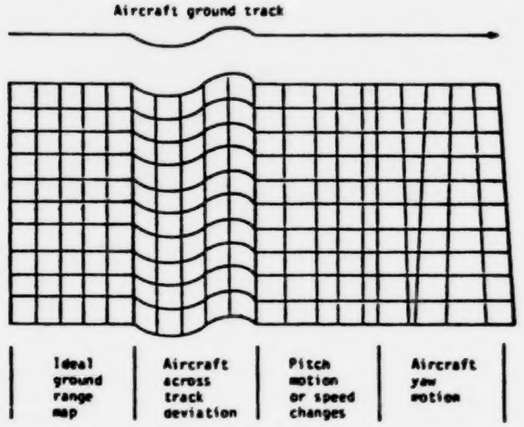

Aircraft ground track
Ideal ground range map
Aircraft across track deviation
Pitch motion or speed changes
Aircraft yaw motion

FIGURE 3.28 SLAR MAP OF SQUARE GRID WITH UNCOMPENSATED AIRCRAFT MOTION
(American Society of Photogrammetry, 1975)

meters of two representative systems operating at X and Ka-band frequencies. The resolutions given in Table 3.15 meet conventional mapping standards at scales of 1:250,000 and 1:500,000 (X-band) and 1:100,000 (Ka-band). Meeting these standards requires improved accuracy in the determination of platform parameters; aircraft altitude and attitude sensors from which signals are recorded simultaneously with image signals. The allowable limits of platform motion shown in Table 3.16 indicate that positional accuracy of up to 50 m is required for mapping with an X-band system, while 10 to 12 m is needed for the Ka-band system. The "yaw" must be determined to better than 1 milliradian, while the degree of "pitch" must be determined between 5 and 20 milliradians.

Typical parameters for two real-aperture systems given in Table 3.15 have different applications. One system is designed for small scale mapping (1:250,000), the other for larger scale mapping (1:100,000). Limitations are imposed by the characteristics of the imaging system. Good cathode ray tubes (imaging tubes) can record about 1000 to 1500 lines in the horizontal or vertical direction. For a 12 centimetre diameter tube, this results in a resolution of 10 to 15 lines/mm. Thus, a required range, for example, of 60 km, provides a resolution on the screen of about 50 m, which corresponds to a pulse length of 0.3 microseconds. High resolution systems use pulse lengths between 0.06 and

TABLE 3.15

TYPICAL S- AND K_a-BAND SLAR PARAMETERS

	X-band	K_a-band
OPERATING FREQUENCY (GHz)	9.5	35.0
AERIAL LENGTH (metres)	4.6	4.0
TRANSMITTER PEAK POWER (kilowatts)	100.0	50.0
PULSE REPETITION FREQUENCY (seconds^{-1})	2500.0	3800.0
PULSE LENGTH (microseconds)	0.2	0.1
RESOLUTION:		
across track (metres)	30.0	20.0
along track (metres/kilometre)	8.0	2.7
SIZE (without aerials) (cubic metres)	0.35	0.4
WEIGHT (without aerials) (kilograms)	155.0	156.0

TABLE 3.16

ALLOWABLE PLATFORM MOTION

SLAR Frequency	For Scale	Height (km)	Positional Accuracy			Angular Accuracy	
			(m) Along Track	(m) Across Track	(m) Altitude	Yaw (mrad)	Pitch (mrad)
X	1:250,000	8.5	25	30	40	0.6	2.7
X	1:500,000	8.5	50	60	80	0.7	5.5
K_a	1:100,000	0.5	10	16	16	1.0	20.0
K_a	1:100,000	1.0	10	16	16	1.0	10.0
K_a	1:100,000	2.0	10	16	16	0.6	5.0

0.1 microseconds for a resolution of 10 metres. Thus, a gain of resolution by a factor of two will result in a reduced image range.

Coverage in both the near and far ranges requires the use of multi-range systems, resulting in high sensor costs. A synthetic aperture system will also require a second channel for longer ranges, since such systems are usually designed for mapping at short ranges (between 5 and 10 km).

SLAR systems inherently average more independent samples than SAR, providing better grey scale resolution. However, it is possible to collect fine spatial resolution SAR data, and subsequently improve grey scale resolution by averaging neighbouring resolution cells, which ultimately results in a lower spatial resolution. In SAR, if the maximum available synthetic aperture length (L) is used in processing, then the resulting imagery is termed single-look, which corresponds to one independent sample and a resolution of, say, D. However, if only part of this length is used, say (L/N), the resulting intensity values are averages, and n-look imagery is produced (n-independent samples are averaged) with a resolution cell size of n x D.

The doppler sampling requirements of SAR systems place a limitation on the achievable swath width. Without this inherent limitation, swath widths are easily varied with SLAR. Consequently SLAR offers greater flexibility in terms of data collection. In addition, to achieve fine resolution with SAR systems, very severe motion stability requirements (less than one wavelength over the synthetic aperture distance) exist. These restrictions are more severe than those shown in Table 3.16 and flight parameters must be continually monitored to provide motion related compensations required for the processing of SAR data.

SAR data requires processing to provide the final radar image and processing units can be either optical or digital, in keeping with the data recording method used. Optical processing of data in a ground facility has been the accepted practice for many years. However, digital recording and processing systems can now provide real-time data onboard the aircraft and digital processors are capable of bulk processing data in 1/4 real-time. SLAR systems provide imagery in real-time onboard the aircraft on a T.V. monitor and also in hard copy prints.

The discussion, in the preceding paragraphs, of the operational characteristics of imaging radar systems (SLAR and SAR) shows that the quantity of data generated is directly proportional to the spatial resolution of the system. Thus, the processing and interpretation time increase with a decrease in resolution cell size. SAR is the only system capable of acquiring high resolution data throughout its entire range, but swath widths achievable are limited, the initial cost of the radar and data processing systems is high and the capability to produce high quality real-time data is limited.

The spatial resolution of SLAR systems is relatively low and decreases in the range direction. Swath widths of up to 100 km are readily achievable, the radar systems have been proven over many years of operation, are simple to operate and produce high quality, real-time data.

Table 3.17 gives specifications for various airborne radars.

3.3 Remote Sensing Capability for Oil Spills

A number of countries have mature programs that utilize remote sensing technology for oil spill detection, monitoring and identification. These are technically advanced countries with ocean coastlines and offshore petroleum activity. The remainder of this sub-section provides an outline of the state-of-the-art airborne sensor systems applied to oil spill sensing nationally and internationally, and demonstrates the potential for using the same sensors in a ground-based mode.

3.3.1 National Airborne Remote Sensing

Canada, through a number of research and development programs initiated by various government departments, has acquired considerable expertise in the remote sensing of oil spills. Most of the research and development has been carried out by the Canada Centre for Remote Sensing (CCRS), under departmental and interdepartmental mandates; a number of oil spill sensors have been developed and tested

TABLE 3.17 EXAMPLES OF SOME COMMERCIALLY AVAILABLE AIRBORNE RADARS

ORGANIZATION OR MANUFACTURER	APERTURE	TYPE	FREQUENCY OR WAVE LENGTH (cm) (GHz)	TRANSMITTER PEAK POWER	ANTENNA GAIN	ALONG TRACK BEAM WIDTH	DEPRESSION ANGLE	MAX RANGE	PULSE WIDTH	RESOLUTION		RECORDING	WEIGHT (kg)	POWER	POLARIZATION
										RANGE	AZIMUTH				
ERIM	synthetic	X-band L-band	9.350 (3.2 cm) 1.315 (22.8 cm)	1 Kw 5 Kw	28 db 16.5 db	1.1° 7°	0-90 0-90	24.1 km 24.1 km	3 μsec 2 μsec	1.5 m 2.3 m	2.1 m 2.1 m	film, single channel real time processor (optional)	1635 (total)	4.8 kVA	HH, VV, HV, VH
SLAR		X-band	3.5 GHz			Antenna 4.4°		5-15 m				analog (FM) or digital			VV, HH, VH, HV
SLAR CSDS-94		X-band		45 Kw min		9° for vertical polarization .45° for H polarization		25 to 5 km swath coverage	0.2 ± 0.025 μsec	100 ft 30 m	95.6 ft/s 30 m	TV monitor as rolling map display - 9" film			
Microwave Scatterometer		Ryan Model 720 slotted guide phased array	13.3 (2.25 cm)	2 Watts	30 db	3° (broadside)	120° (fore/aft)			.052 x (altitude (m))	.26X (ground speed (ms^{-1}))	instrumentation tape recorder (analog)	Antenna 16 electronics 11	110V 400 Hz 2.8A 110V 60 Hz .3A	HH, VV, VH, HV
Westinghouse	real	APD-7	8.6 mm					21 km		8 km	1.7 R km	real time display & film	225	3170 W	HH
Motorola	real	APS-94D	32 mm 56 mm					100 km		30 km	1.7 R km 15 R km	real time display & film	235	1940 W	HH, VV HH, VV
EMI	real	P391 and X-band	8.6 mm 32 mm					28 km 63 km		15 km 30 km	3.5 R km 16 R km	real time display & film	195	980 W 800 W	HH HH
Ericsson	real		32 mm	10 Kw	31 db			20 km	.5 μsec	75 km	7.5 X 8 km	real time display & film			VV
Goodyear	synthetic	APD-102	31 mm					37 km		15 km	15 km	film	232	2931 W	HH

(O'Neil et al, 1981). Much of the expertise has been transferred to the private sector and industry now possesses a number of successfully demonstrated sensing systems. However, as part of their ongoing program, CCRS continues to respond to oil spill events.

Government remote sensing capabilities exist at both the federal and provincial level (see Table 3.18), but are general in nature and not specifically oriented toward oil spill sensing. The Atmospheric Environment Service, Environment Canada, operates two Electra aircraft for sea ice patrol purposes. In situations where their normal operations will not be jeopardized, they are available on a request basis to assist in oil spill sensing. The Department of National Defence operates a number of aircraft for defence purposes, including maritime patrol and aerial reconnaissance aircraft. DND has demonstrated a cooperative attitude with respect to oil spill sensing on a non-interference with military commitments basis.

At the provincial level, the Ontario and Maritime governments have developed airborne remote sensing programs. The Ontario government administers an operational and developmental remote sensing program through the Ontario Remote Sensing Centre, which supports provincial government requirements, but has the mechanism to contract their airborne systems for non-government, private sector use. The Maritime governments through a quasi crown corporation that falls under the auspices of the Council of Maritime

TABLE 3.18 GOVERNMENT AIRBORNE REMOTE SENSING CAPABILITY

AGENCY	AUTHORITY	PRIMARY PURPOSE	AIRCRAFT	SENSORS	AVAILABILITY FOR OIL SPILL SENSING
Canada Centre for Remote Sensing (EMR)	Federal	Research & Development	Convair 580 Falcon DC3 (2)	- LLLTV - Dual channel line scanner - Multispectral line scanner - Four channel research SAR - Laser fluorosensor - AGTV & cameras - MEIS (experimental)	On request, cost recovery basis
Ontario Centre for Remote Sensing (Ministry of Natural Resources)	Province of Ontario	Support Ontario governmental programs	Navaho Chieftan	- Daedalus IR line scanner - 2 Vintens (70mm) & (9" x 9") - opt.- 4 Hasselblad (70mm) - Aerial video	Contract basis
Atmospheric Environment Service (Ice Branch)	Federal	Ice Patrol	Electra (2)	- APS 94D Radar - Bendix thermal mapper - 70mm camera	On a non-interference basis with ice patrol flights
Department of National Defense (DND)	Federal	Military Patrol Duties	Aurora CF104	- Reconofax XIIIA line scanners - Other classified military equipment	Normally not available due to military commitments but will assist where possible
Atlantic Canada Airborne Sensing (Crown Corp.)	Council of Maritime Premiers	Support Maritime Provinces	PA23 Piper Aztec	- LLLTV - B&W daytime TV (& colour) - FLIR - Cameras	Contract basis

Premiers has also equipped an aircraft for remote sensing purposes. Although their aircraft was designed for all purpose remote sensing, it has been optimized for ocean sensing, and is suitable for oil spill work. Through inter-government arrangements, this aircraft is available for government contract work and commercial hire.

The Canadian public sector has a long history of remote sensing activity utilizing air survey aircraft equipped with aerial cameras. Recently, some companies have increased their remote sensing capability by installing additional sensors (Table 3.19). These are the most prominent commercial operators in Canada who are dedicated to providing remote sensing services and possess aircraft and sensors applicable to oil spill sensing. Other companies may exist, that operate suitable sensors in addition to cameras, but their regional and national presence has not yet been demonstrated.

3.3.2 International Airborne Remote Sensing

Several countries have developed remote sensing programs with an emphasis on oil spill surveillance. The most predominant are the United States, Sweden and France.

The United States Coast Guard is the American agency tasked with oil spill responsibility. They have been active in the development of an airborne remote sensing system since the early 1970's (Meeks et al, 1977). The first system developed was the Airborne Oil Surveillance System, AOSS (Maurer et al, 1977). Its purpose was to detect, map,

TABLE 3.19

CANADIAN PRIVATE SECTOR REMOTE SENSING CAPABILITY

COMPANY	AIRCRAFT	SENSORS	INTERESTS
MARS Aerial Remote Sensing Limited	Grumman GI	- Motorola APS 94 D - SLAR - Aerial Cameras - IR Line Scanner	Regional National
Intera Technologies Limited	Cessna 411 Cessna 310 Piper Navaho	- Daedalus IR Line Scanner (single & dual) - Aerial Cameras - LLLTV - SAR - SLAR	Regional National
Aerial Mapping & Photography Limited	Beechcraft Super King Air B-200	- Zeiss RMK A 15/23 Aerial Camera - Radar Altimeter (FP-RI) - LLLTV - TV (B&W) - B&W Support Photo Lab	Regional

quantify and classify oil spills. As an integrated sensor system it had real time, all-weather, and twenty four hour operational capability. Its operational role was to detect potential oil spill violators (ships), examine areas in the vicinity of these potential violators to detect oil slicks, map detected oil slicks (location and size), and to document those violators for legal action (Edgerton et al, 1975). In addition to its use for oil spill sensing, AOSS was also designed for uses such as search and rescue, enforcement of laws and treaties, and iceberg patrol. Table 3.20 lists the sensors mounted in the AOSS aircraft. The initial test aircraft was a Grumman Albatross (HU-16E) but the developed system was installed on a Lockheed Hercules aircraft (HC-130B).

The AOSS system was the forerunner of the system presently used by the U.S. Coast Guard. The new system is called the Airborne Remote Instrumentation System given the acronym "Aireye". It was installed in the early 1980's on a Falcon aircraft (HU-25A), a medium range search aircraft. The Aireye sensor package is listed in Table 3.21 (White et al, 1979). Major additions to the system include an active gated television and the surveillance system operator console; the sensor suite integration occurs when control and signal processing is carried out. The Aireye system is the world's state-of-the-art airborne remote sensing package for oil spill sensing.

TABLE 3.20

U.S. COAST GUARD'S AIRBORNE OIL SURVEILLANCE SYSTEM (AOSS)

Aircraft: USCG HC-130B

SLAR

Frequency	. X band (tuneable)
Peak Power	. 45 kw min
Pulse Width	. 0.2 ± 0.25 μsec
PRF	. 750 ± 10 ppm
Coverage	. Horizontal: 0.9° between half-power points . Vertical: depressed 3° to 45°
Range	. 50 km (27 nm) . 25 km (13.5 nm)
Resolution	. 30 m (98 ft)
Display	. Photo radar map and colour TV monitor
Target location	. Printout of selected target computer longitude and latitude

Line Scanner

Spectrum	. UV - 0.32 to 0.38 μm (channel 3) IR - 8 to 13 μm (channel 1) - 8 to 9.5 μm (channel 2)
Scan coverage	. 100° across direction of flight with ±15° roll stabilization 2.5 mrad in direction of flight
Scan rate	. 5,000 rpm 83.3 scans per second
Detectors	. IR - Hg:Cd:Te UV - P-13 photomultiplier
Display	. Photo map and colour TV monitor
Airborne Remote temperature (data processor computed value)	. Printout of computed temperature with longitude, latitude, altitude, heading and time

Passive Microwave Imager

Frequency	. 37 GHz
Scan coverage	. Forward 120° across direction of flight in 45° cone axis
Scan rate	. Variable from 8 to 88 rpm as determined by aircraft V/H ratio

Passive Microwave Imager (continued)

Display	. Colour TV monitor, linear display corrected from circular scan and smoothed by data processor
Recording	. Magnetic tape recorded and/or video taped when displayed on TV monitor

KS-72 Camera

Photo coverage	. Area across line of flight or at 45° to port side of aircraft
Field of View	. 3-inch lens: 73°44' . 6-inch lens: 41°06' . 12-inch lens: 21°14'
Frame rate	. 6 frames/second max. Variable with aircraft speed and altitude
Photosize	. 4½ x 4½ inches
Film capacity	. 500 feet with standard cassettes
IMC accuracy	. From ± 77% at 0.10 inches per second to ± 2% at 12 inches per second
Exposure	. Automatic exposure control with compensation for installation lens and cloud coverage
Night mode operation	. Shutter tripped by light from flare or strobe

Offline Printer

Paper type	. Electroresistive
Paper dimensions	. 8½ inches wide (approx. 300 feet long)
Printing format	. 80 characters per line, 10 characters per inch, 6 lines per inch
Printed character format	. 7 x 9 dot matrix, 96 printable characters
Printing speed	. 120 characters per second max. 1 line per second in system operation

(Meeks et al, 1977)

TABLE 3.21

AIREYE (U.S. COAST GUARD'S AIRBORNE REMOTE SENSING INSTRUMENTATION SYSTEM)

Aircraft: Falcon 206 jet aircraft
(military designation HU-25A)

Characteristics

Length	17 meters
Wing span	16 meters
Height	5.4 meters
Wing area	40.5 square meters
Engines	2 Garrett ATF
Dash speed	670 km/hr

SLAR - New generation AN/APS-94 radar

Peak transmitter frequency	200 kilowatts
Frequency	9250 megahertz - 9250 to 9290 MHz tuning range
Pulse width	0.2 microsecond
Pulse repetition frequency	750 pulses per second
Azimuth half-power beamwidth	0.9 degree, one way
Elevation shaped pattern coverage	-1.5 to -45 degrees
Peak gain	35 decibels (dB)
Depression angle of beam peak	1.5 degrees
Receiver noise figure	4.16 dB
Receiver bandwidth	6 MHz
Transmitting microwave losses (from magnetron to antenna)	2.2 dB
Receiving microwave losses	1.95 dB
Ranges available	24/32/64/128 km

IR/UV Line Scanner

Infrared response band	7.6 to 13.8 micrometers
Infrared detector angular resolution	2.5 milliradians

IR/UV Line Scanner (continued)

Infrared noise equivalent temperature difference	. 0.2° Kelvin
Ultraviolet response band	. 0.320 to 0.400 micrometers
Ultraviolet detector angle resolution	. 5.0 milliradians
Ultraviolet channel sensitivity	. 17 dB signal to noise ratio (specific parameters)
Altitude operating range	. 150 to 3,600 meters
Velocity/altitude ratio for contiguous line to line IR ground coverage	. 0.20 radian/second

Airborne Data Annotation System (AOSS)

Key element is the production of imagery that can be used to prosecute pollution violators.

KS-87B Camera

Lens			
Cones	15 cm	30 cm	45 cm
Focal length	15 cm	30 cm	45 cm
Resolution	50 lines/mm	45 lines/mm	65 lines/mm
View angle	41°06'	21°14'	14°14'

Number of exposures	. max of 6 per second
Film format	. 11.4 cm x 11.4 cm
Effective shutter speeds	. variable 1/60 to 1/3000 second

AGTV

Gimbel coverage	. + 15° to 84° elevation ± 220° azimuth
Angular velocity	. 60°/second (slew 199°/second)
Diagonal field of view	. 18.2°, 6.5°, 2.3°
Output power at 722.9 nm	. 1 watt at 7.8 KHz PRF
Weight	. 95 kg
Power	. 425 watts, 28 VDC 1450 watts, 110 VAC, 400 HZ
Resolution	. 28.5 lines/mm at 1 x 10^{-4} foot candles
Photocathode response at illuminator wavelengths	. 40 MA/W

Surveillance System Operator (SSO) Console is a sensor computer which performs five primary functions:

- automatic pointing of the AGTV
- generation of a map displaying sensor and "target" positions
- implementation of display and control functions
- digital interface of the airborne data annotation system to the aircraft data bus, and
- monitoring of sensor and system performance and failure alerting.

The Swedish government has taken an economical approach to solving their oil detection problems. They have developed a package (Table 3.22) with similar sensors to Aireye, but operating with real time displays and no extensive data storage/retention package. They tested two systems on separate aircraft. The prime sensor on one aircraft was a side looking airborne radar and on the second, an ultraviolet/infrared line scanner. Both aircraft were equipped with cameras and navigation systems. After a two year performance evaluation, the Swedish Coast Guard integrated these two sensors and installed them on a third aircraft. The Swedish program is continuously evolving, and future plans include an upgraded sensor package with a passive microwave imager, a laser fluorosensor, LLLTV and a modified SLAR system.

The French government, in response to coastal requirements, has undertaken a series of experiments. Prototype developments in the mid-1970's resulted in an airborne remote sensing system with a real-time downlink to a ground based facility (Table 3.23), (Burkhalter & Meyer, 1979). The system basically consists of an infrared line scanner supported by two 70 mm aerial cameras and the capability to utilize a television camera. The French system, as first designed, did not have an all-weather capability. Plans have been made to test and incorporate a SLAR system in the early 1980's. The success level of the French program has

TABLE 3.22

SWEDEN'S AIRBORNE OIL SPILL SURVEILLANCE SYSTEM

Aircraft: Cessna 377 Skymaster

Camera System

	. one hand held for oblique photographs
	. one vertical

Real Aperture SLAR

Antenna	. slotted waveguide, three metres long
Polarization	. vertical
Frequency	. X-band, 94 GHz
Peak Power	. 10 kilowatts
Ground resolution	. 75 x 75 metres
Display	. real time TV display 20 x 20 km

IR/UV Line Scanner

Type	. Daedalus DS-1200
IR channel	. 8 to 14 micrometers
UV channel	. 0.3 to 0.4 micrometers
Resolution	. 5 milliradians
Field of View	. 80 degrees
Scan rate	. 40 scans per second

(Backlund, 1979)

TABLE 3.23

FRENCH SURVEILLANCE SYSTEM

Aircraft: Cessna FTB 337

Max speed	. 200 knots
Work speed	. 140 knots
Max range	. 1,000 nautical miles
Flight duration	. 4 hours

Supercyclope SCC 3100 Infrared Line Scanner

Manufacturer:	Societe Anonyme de Telecommunications (SAT)

Analysis Head:

Spectral band	. 8 - 12 microns
Detector	. Hg:Cd:Te cell cooled by liquid nitrogen
Scanning angle	. 90°
Scanning speed	. 240 scans/second
Spatial resolution	. 1.5 milliradians
Roll correction	. ± 15°

Additional Features:

- An electronic rack
- A control box
- An oscilloscope
- Video tape recorder
- Rolling-type video display
- A radio transmitter

Support Systems

- two Hasselblad 500 EL cameras (70 mm)
- 24 x 36 camera equipped with date and time annotations
- optional TV camera

Ground Receptor System (fixed and mobile)

- a radio receiver
- interfacing rack
- rolling video tape display
- laser beam recorder
- video tape recorder

(Burkhalter & Meyer, 1979)

led to considerations for a future increase in the number of surveillance aircraft (Burkhalter & Meyer, 1979).

3.4 Assessment of Sensor Capabilities

To provide an assessment of the capabilities of each sensor, a verbal matrix was constructed (Table 3.24). This matrix qualitatively assesses the various sensor systems described in this section. It will also be used in the next chapter, the evaluation chapter, in conjunction with the previously presented quantitative information.

The horizontal divisions of Table 3.24 identify the various sensing systems used. Sensor system headings are; human observation, cameras, television, radiometers, line scanners, FLIR, Fraunhofer Line Discriminator, AGTV, microwave and radar.

The first vertical group is system operation. The first sub-group is concerned with previous aircraft mounting of the sensor in question. A yes or no statement will be found for each type of sensor system. The same yes/no statement follows for the third sub-group describing the sensor previously used in a surface sensing configuration. Sub-group two and four, dealing with the availability of a sensor, are classified as commercially available, developmental or experimental. The fifth sub-group defines whether or not a sensor system can be adapted to a surface based mounting. Yes/no decisions are made. This grouping identifies either airborne or surface sensors suitable for ground based measurement of chronic oil discharge.

The second vertical grouping describes the type of observation required and assesses the sensor's capability (in its present configuration) to sense chronic oil discharges. The classifications used are good, fair and poor. A "good" indicates a sensor has a high potential capability (for specific observations), fair means some capability exists and poor indicates little or no capability. A monitoring and/or detection operation is more specific than a general surveillance operation and doesn't require as much coverage by the sensor. Thickness of the oil and type of oil are self-explanatory.

The third group is oil type. Division is based on heavy refined petroleum products, crude oil, and light refined products. The fourth grouping, other, includes materials such as petroleum in drilling debris and drilling muds. The classifications used are yes, possible, and no.

The fourth grouping is concerned with the placement of the oil in the water. Three surface conditions exist, continuous, discontinuous and mixed. Continuous would be a 100% surface cover, while discontinuous would be a fractional surface coverage. Mixed, indicates oil on the surface, becoming mixed or incorporated into the water surface layer. Near surface oil would be oil that has sunk below the surface of the water but remains relatively close to the air/water interface. Oil below the surface suggests oil located substantially below the air/water interface (or surface layer). Codes used are yes, possible, and no.

The fifth grouping identifies how quickly data is available from the various sensors. Real-time means immediately, while near real-time means there may be a small time delay due to design specifications or data processing. The third code "after landing" means that some form of ground support is necessary for the processing of data. "After landing" data is often used to reevaluate the real-time data that was recorded. Systems meeting a required capability will be identified with an "X".

The sixth group consists of influencing environmental conditions, sub-divided into atmospheric and oceanographic. The sensor's performance under the conditions given are described as good, fair and poor. These general classifications recognize that sensors may operate under all conditions to some limited degree.

Group seven identifies with an "X" the total range over which each sensor operates.

SECTION 4

EVALUATION

This section of the report deals with the evaluation of sensors and their suitability for chronic discharge measurement. Accordingly, scenarios will be developed to define the pertinent possibilities whereby sensing of a discharge will be necessary and useful. The second step will be to identify those sensors that best meet each scenario sensing requirement. Identified will be: sensors that are presently available, potential existing sensors that require further development and testing and promising new technology available. The third step in the evaluation process will be recommendations concerning use and/or development of chronic discharge sensing packages.

4.1 Chronic Discharge Scenarios

The most important consideration is the amount of oil spilled and its disposition within the water environment. As previously stated, a chronic discharge would constitute 1 to 5 barrels spilled daily, or the cumulative amount of equivalent oil released from a point source over a time period of as much as one year. This represents a very small amount of oil when compared to accidental or catastrophic spills. If this amount of oil was spilled over a long period, on a continuous basis, it is very unlikely that a slick or sheen would appear on the surface, as most of the discharge would be incorporated into the water column. If the same volume of discharge occurred almost instantaneously, the familiar sheen or slick could appear for a finite time period. Therefore, with respect to limited quantity spills, there is a time component which governs their visibility characteristics.

With respect to the above scenarios, it is expected that all types of oil may be spilled. The heavy, refined products (specific gravity greater than 1) would remain submerged, with very little becoming incorporated into the water column. Tar balls could form and sink. Crude oil, depending on the amount, would form a slick and/or incorporate into the water column. Light refined products would essentially evaporate and the residues and/or some of the original spill would enter the water column.

Spillover or drilling wastes occur in minute quantities and probably enter the water column; quantities will never be sufficient to form a slick. In such small quantities, weathering of the oil will not be a major factor, as other processes will disperse the small amounts involved. If the volume of oil is sufficient, an emulsion could form in rough sea states, but if this occurred, the quantity of "mousse" would be very small. Amounts of oil large enough to form a sheen or slick could disperse in several forms.

The surface discharge could be continuous or discontinuous and under certain conditions, mixing with the surface layer could occur. Depending on oil type, the pollutant could move into the near surface, or below the surface layer. All aspects of the environment, as listed in Table 3.24, could be encountered, and must be considered, when an evaluation of sensor systems is carried out.

One further consideration is the distance factor. A chronic discharge normally occurs from a point source and the discharge extent from the source will not be great. Therefore, the time required for dispersion processes, under different environmental conditions, becomes important. Under calm conditions, a radius of 100 m could be a predictable range; under less than desirable conditions, an elongated dispersion would occur, and possibly extend to a range of 500 m.

In summary, two sensing scenarios develop for chronic oil discharges. The first is the formation of a sheen or slick, leaving visible evidence on the surface that will be subject to the normal dispersion processes, influenced by environmental conditions and oil type. An outer limit of 500 metres from the source can be assumed. The second is point source embodiment with the water column, which will occur very quickly. The distance factor becomes unknown because once it is incorporated with the water, the pollutant will be subject to the water circulation patterns.

Thus, one scenario will encompass small discharges that have visible evidence of their occurence and the second, small discharges that are invisible and must be located.

4.2 Sensor Evaluation

Sensors must be evaluated for two cases; visible discharges and invisible discharges. The first will have great similarity to sensor suites used from aircraft for normal oil spill sensing while the latter will require imaginative development.

4.2.1 Visible Discharges

Under normal daylight, and calm sea conditions, a human observer will be able to visually detect and define the extent of very small spills, providing there is a sufficient quantity of oil to form a sheen on the water surface. However, under cover of darkness, or the degradation of atmospheric conditions through the presence of cloud, fog or precipitation, visual observation capabilities will range from marginal to nil. Similarly, a change in oceanographic conditions from the ideal calm, to rougher seas, will reduce visual observation capabilities. At approximately sea state 3, significant dispersion will preclude further visual observation. The introduction of ice cover into the observed area also presents an insurmountable obstacle to visual observation. Since the capabilities, and as explained above, the shortcomings of visual observation methods , are easily defined and are generally understood, visual observation has been established as a base-line with which to compare other sensors during the conduct of the following evaluation.

4.2.1.1 Photographic Cameras

Operating Parameters

Photographic cameras record energy in the ultraviolet, visible and near infrared regions of the electromagnetic spectrum and therefore, are capable of operating only under clear weather and good light conditions. The only advantages presented by cameras over visual observation are their ability to record a permanent image and their extended spectral response into the near infrared and ultraviolet regions. For the sensing of oil spills, no particular benefits are evident in the utilization of near infrared wavelengths; energy in the ultraviolet region provides excellent discrimination between oil and water. However, the lenses of standard aerial cameras will not pass ultraviolet light and they must be fitted with special quartz lenses and filters.

Operational Considerations

Although all types of aerial cameras are capable of adaptation to ship, rig or other ground based platforms, it is suggested that the larger metric and panoramic type cameras are much too large, heavy and expensive to be utilized for the purpose under discussion. Smaller format (70 mm) reconnaissance cameras are relatively inexpensive, light, rugged and have available, a wide variety of lenses of varying focal lengths that can be interchanged easily and rapidly to adapt the angle of coverage to fit a particular scenario i.e. short focal length to cover a wide area; longer focal lengths to cover, at a useful scale, areas that may extend to some distance from the point of acquisition. Quartz lenses that pass ultraviolet wavelengths are also readily available on an off-the-shelf basis.

As with a human observer, cameras are restricted under certain circumstances in their look direction. Since light with the incident angle of the illuminating source (the sun) reflects from a water surface at an equal angle, the reflected "glare", if it falls directly on the camera lens, will prevent the acquisition of usable data.

Since the camera will be required to operate under a wide variety of light conditions, it must be equipped with auto-exposure control. For recording of visually observed slicks it may be manually triggered, but when used in a surveillance mode, it should be fitted with an intervalometer which will activate the system at pre-set intervals.

Photographic film used as a recording medium in the camera is perhaps the most permanent and easily utilized medium in existence. Unfortunately, unless processing facilities are available in close proximity to the data recording area, there will be a time-lag between the recording period and the perusal of the recorded data. Generally, this should not be a severe limitating factor.

Mounting

For the recording of specific events, reconnaissance cameras are small and light enough to be hand-held. In a surveillance mode, the cameras must be fixed to a rail or bulk-head, and in most instances will be required to look at an area down-wind from the source of the pollutant. Unfortunately, winds may vary in speed and direction throughout an operational period. Unless a high, platform center, mounting position, which will permit the rotation of the camera to cover the required area can be utilized, it will be necessary to locate mounting stations and power outlets on at least four sides of the platform. Rapid mounting and adjustment of the camera can be facilitated by fitting it with a simple mount that will hinge in one direction to permit the rotation of the camera in its vertical axis. Rotation is required from the horizontal to the vertical (lens axis); a secure locking device is mandatory to firmly hold the camera at the desired angle of depression. The base of the mount may be equipped with one side of a wedge-plate and mating wedge-plates may be fixed vertically at pre-determined positions on the platform. Relocation of the system can be accomplished by lifting of the system from one wedge-plate and sliding it in a wedge-plate at the new position.

Level of Expertise

a) Operation - No particular level of expertise is required to operate a reconnaissance type camera fitted with an auto-exposure device. Training in loading and unloading film in the magazine can be accomplished in less than an hour, using dummy film to practice the operation.

b) Interpretation of Data - Interpretation of data is relatively simple. Some training in the recognition of differences in image colour, density and shape that indicate the presence of a pollutant is required. Between five and ten hours of theory and practical instruction should be sufficient for most individuals to acquire interpretation skills applicable to first phase interpretation. Interpretation of doubtful or disputed images should be carried out by fully trained photo-interpreters who are capable of re-processing and/or digitizing the data to permit filtering, edge enhancement and/or other manipulations that improve oil/water discrimination.

Evaluation Summary

Photographic cameras are easily adapted to ground-based platform mounting and when operating in the visible and ultraviolet regions of the spectrum, are capable of imaging a visible discharge and mapping its aerial extent. They are limited to operation under clear weather, daylight conditions and to some extent, look direction with respect to incoming radiation. In view of their capability to record a permanent image of pollutants and therefore, provide irrefutable evidence of their presence, it is suggested that they be utilized whenever possible, in conjunction with other sensors, to record detected events.

4.2.1.2 Television Cameras

Operating Parameters

Both conventional and low light level television cameras are suitable for sensing visible pollutant discharges. As with photographic cameras, they operate in the ultraviolet, visible and near infrared region of the spectrum and may be similarly filtered to utilize ultraviolet light for the discrimination of oil from a water background. In general, the sensitivity of television cameras to reflected energy is somewhat higher than those of the human eye and/or sensitivities available in photographic films. Through the use of various types of imaging tubes and the addition of image intensifiers, television cameras can be purchased that range in sensitivity from that considered "normal" to an increase of 32,000,000,000:1 (LLLTV). Cost of systems is generally proportional to sensitivity and therefore, the mode of operation and sensitivity required, must be considered when systems are to be purchased. All television systems are subject to image degradation by cloud, fog or precipitation within their viewing range. However, LLLTV cameras will acquire acceptable data in clear weather conditions, with illumination ranging from bright sunlight to one-quarter moonlight. Correct image intensity is maintained throughout the full range by means of an auto-iris control.

Operational Considerations

All types of television cameras are ideally suited to operation from a ground-based platform. However, as with the human observer and photographic cameras, their into-sun viewing angle is restricted. This is of particular significance for most television systems, as direct sunlight on the lens will burn, and permanently damage, the tube.

The auto-iris function of the LLLTV system presents a distinct advantage, as it assures the acquisition of optimum quality data over wide ranging, rapidly changing, illumination levels. Television cameras may also be equipped with a wide variety of lens systems; some provide a zoom capability of up to 10 X. This assures adequate aerial cover, at required scales, for both near and far ranges. As with photographic cameras, television cameras may be hand-held and activated manually to record specific events. For extended surveillance operations, an interval timer which "bursts" the camera for short periods at preset intervals, will extend the operating time-range on a single tape load.

Unfortunately, tape used as the recording medium cannot be considered permanent, as data may be degraded or destroyed if the tape is subjected to a magnetic flux created by electrical currents or permanent magnets. Care in handling is therefore essential. Many types of tape recording devices may be utilized but it is suggested that a standard

VHS cassette recorder is the most versatile and easily operated system available. Data may be viewed in real-time by the addition of a monitor to the recording system, or examined at a later date by play-back through a monitor or standard television. Equipment is available to produce hard-copy images on film or paper, from the tape.

Mounting

All of the restrictions and suggestions regarding the mounting of photographic cameras, as outlined in Section 4.2.1.1 above, apply directly to the mounting of television cameras. In addition, a secure mounting plate or rack must be provided at each position to accommodate the cassette recorder, and if applicable, a monitor. Electrical power outlets and/or an extension cord capable of reaching a suitable outlet near each operating position, is also mandatory.

Level of Expertise

a) Operation - Operation is extremely simple and requires minimal instruction to operate the tape recorder, set the timer and turn on the camera. Operators should also be instructed in the handling of both raw and recorded tape.

b) Interpretation of Data - As for photographic data, interpretation is relatively simple. Several hours of instruction on the significance of various grey-levels, or tones, should permit any individual to perform a reasonably accurate first phase interpretation of the data.

Final interpretation will require the expertise of an experienced interpreter.

Evaluation Summary

Television cameras are readily adaptable to mounting and operation on ground-based platforms, and are capable of recording visible pollutant slicks on the water surface. Automatic exposure control and the addition of zoom lenses makes them extremely versatile. In view of the day/night operational capabilities of LLLTV systems, it is suggested that their extra cost is justified and that they be considered above all other television systems as a prime surveillance instrument.

4.2.1.3 Radiometers

Operating Parameters

Radiometers are divided into two groups. Photometers measure reflected energy in the ultraviolet, visible and near infrared; infrared radiometers measure emitted thermal radiation from a target. Although radiometers are capable of receiving and recording data within specific spectral bands, they are non-imaging, and their prime function is to measure the intensity of energy collected. Accurate measurements are obtained through correlation with internal, or external, calibration sources. Photometers will only function under daylight illumination conditions; infrared radiometers have a day/night operating capability. The presence of moisture in the air severely degrades the sensing capabilities of all types of radiometers.

Operational Considerations

Radiometers in general have very narrow angles of view ranging from a few milliradians up to 2°. Since they measure the reflected energy integrated over the total area of their "footprint" on the surface sensed, they will not indicate the presence of a pollutant/water interface. The size and shape of the footprint is critical. Mounted in a vertical position it is circular, but becomes an ellipse when the instrument is angled. This fact may lead to errors in quantitative measurements. Photometers are particularly susceptible to erroneous readings being obtained through the inclusion of sun-glint, specular reflection, etc. and therefore should be positioned as close to the suspected pollutant source as possible and be mounted in a vertical position. Infrared radiometers may be utilized in a vertical or oblique mode, but caution should be exercised in that the inclusion of hot exhaust gases within their field of view may cause an error in measurement.

The output from radiometers may be in a real-time analogue or digital format and can be recorded on a chart recorder or tape for further evaluation.

Mounting

Radiometers may be configured in a wide variety of shapes, sizes and weights, but should present no serious mounting problems. Wedge-plates may be used as recommended for photographic and television cameras. Provision must be made for securing and powering chart or tape recording devices.

Level of Expertise

a) Operation - Operation of radiometers is automatic and there is no requirement for specialized training. Operators must be capable of loading recording devices, mounting and providing power to the various components.

b) Interpretation - As radiometers are non-imaging, interpretation will consist of viewing, and if necessary, plotting of readings obtained. Interpreters must be aware of the significance of recorded readings and be capable of relating results, to conditions existing on the surface at the time the data was acquired.

Evaluation Summary

Both photometers and infrared radiometers could be used for the sensing of pollutant discharges. However, unless quantitative data is required, they do not present any advantage over televisions or infrared imaging systems. There is undeveloped potential for photometers, in that they can be used to measure fine-line spectra and thus, may be capable of identifying oil types. A Canadian company is also experimenting with a calibrated infrared radiometer system that detects the presence of methane gas through changes in thermal response. Such a system could possibly be adapted as an "event alarm" to give an audible or visible signal and/or activate an imaging sensing system.

4.2.1.4 Line Scanners

Operating Parameters

Line scanners may be configured as single, dual, or multiple channel systems, and as such are capable of recording in very discrete, narrow spectral bands from ultraviolet, through visible and into the infrared thermal region to 14 μm. Their output may be in an analogue or digital form; analysis of a scene may be carried out on an image or using an output signal containing quantitative information.

Moisture in the atmosphere will degrade, or preclude, the acquisition of data within the line scanner's entire spectral response region; only the thermal channels will be operable under night conditions.

Operational Considerations

It is unfortunate that line scanners, as configured for airborne operations, are almost impossible to use on ground-based platforms. They are designed to operate in a vertical, rather than an oblique, position, and depend on the forward motion of the platform to build an image with contiguous scan-lines.

It is possible that, through intensive research and development, certain types of line scanners could be adapted to ground-based use. However, developmental costs would far exceed the benefits accrued in the acquisition of data that can be obtained by using a combination of readily available, but much simpler, sensors.

Mounting

Mounting of line scanners in their present configuration would not present a serious problem. However, the type of mechanical, moving mount that would be required to operate the line scanner in a ground-based configuration, cannot be envisaged at this time.

Level of Expertise

a) Operation - A very high level of expertise is required to operate and maintain line scanners. They require constant monitoring and adjustment of controls, to obtain optimum quality data.

b) Interpretation - A high level of expertise is required in the interpretation of line scanner data. In particular, multi-channel systems (the most useful for discharge monitoring) require considerable experience and training to efficiently select and analyze specific spectral bands.

Evaluation Summary

The capability of line scanners to record data in multiple, discrete spectral bands, makes them the ideal instrument for the remote sensing of pollutant discharges. Unfortunately, in their present configuration, that cannot be easily adapted to ground-based operation. They are costly to purchase, operate and maintain, and a high level of expertise is required for both the operation of the acquisition system and the interpretation of data. No further consideration should be given to this item for the purpose under discussion.

4.2.1.5 Forward Looking Infrared (FLIR)

Operating Parameters

Forward looking infrared devices operate in the thermal infrared region of the electromagnetic spectrum (generally 8 to 14 μm). Data collection is possible under clear, day/night conditions; as moisture content in the atmosphere increases, sensor capability decreases. The data acquisition efficiency of FLIR also degrades with increasing sea state and/or an increase in wind speed. Acquired data is not quantitative.

Operational Considerations

No adaptation is required to utilize FLIR systems from a ground-based platform, as they were designed to be operated from stationary towers, hovering helicopters and boats. For some models, power, gimbal mounts are available to remotely control the look-angle from horizontal to vertical and rotate the sensor through a 180° arc in the horizontal plane. Some models also permit remote selection of either a 28° x 17° wide field of view, to a 7° x 4° narrow field of view which provides a 4 X magnification factor. Thus, both near and far range surveillance requirements can be met.

Output may be viewed in real-time on a monitor, and be simultaneously recorded on a standard VHS cassette recorder for future analysis. Cautions outlined in Section 4.2.1.2 regarding the handling of video tape apply. Controls at the monitor permit contrast and brightness control as well as adjustment of the thermal sensing level, to record the optimal thermal range within the scene.

Mounting

FLIR systems are relatively small and light. Most models enclose the sensing system within a protective casing and are already equipped with their own mount (see above). All restrictions and suggestions regarding mounting of cameras and television systems outlined in Sections 4.2.1.1 and 4.2.1.2 respectively, apply. It should be noted however, that viewing of the real-time image, and full control of the system, may be carried out from a position remote from the sensor.

Level of Expertise

a) Operation - FLIR systems are almost as simple as television cameras to operate and maintain. Training by the manufacturer in operating the detector cooling system will be required, but efficiency in operating of the system to ensure the acquisition of optimal data, can only be acquired through experience.

b) Interpretation of Data - Very little training is required to perform first phase interpretation of acquired data. Four or five hours of instruction using typical video images should suffice. In some instances it may be necessary for a skilled interpreter to clarify results obtained, by comparing them with data simultaneously recorded with other sensors, or applying known oceanographic or meteorological factors that were in existence during the acquisition period.

Evaluation Summary

FLIR systems will provide a day/night capability for the detection and surveillance of chronic oil discharges. Since they do not respond by reflected visible or infrared energy, their look direction is not restricted. Their reception is degraded by moisture in the air created by fog, cloud or precipitation within their viewing area, and erroneous results may be obtained under high wind conditions, or in the presence of warm exhaust gases. As an integral part of the system, gimbals facilitate mounting on ground-based platforms; permit remote operation, and the direction of the sensing system. FLIR systems are considered to possess many of the attributes required for the surveillance of chronic discharges.

4.2.1.6 Lasers

Operating Parameters

Lasers are coherent light sources that may operate in the ultraviolet, visible or near infrared regions of the spectrum. At these operating frequencies, they are most effective under clear atmospheric conditions, but due to their signal coherency, they achieve some penetration through cloud, fog or precipitation at short ranges.

Operational Considerations

It muse be understood that the sole purpose of lasers is to act as an illuminating source that will assist sensors in the acquisition of data. Depending on their signal frequency, lasers may be used to measure the range to a target, penetrate water for bathymetric purposes, or cause certain substances to fluoresce. Fluorescence of oil and related substances occurs when they are illuminated by energy in the ultraviolet region of the spectrum. Lasers and reflected energy recording devices are often combined to create a remote sensing system called a Laser Fluorosensor. Experimental laser fluorosensors have a proven capability to detect, identify and measure the thickness of pollutants on the water surface. There are no successful, commercially available systems.

Mounting

As previously stated, lasers are usually an integral part of some sensing device. The mounting of such systems is outlined where applicable.

Level of Expertise

a) Operation - No particular level of expertise is required in the operation of lasers. Fairly high levels of expertise may be required to operate other sensors into which the laser has been incorporated. Caution must be exercised when operating lasers, as exposure of eyes to certain frequencies, even at long ranges, may cause severe eye damage or total loss of vision.

b) Interpretation - Not applicable.

Evaluation Summary

Lasers provide a day/night illumination source for a variety of sensing systems. The precise control of laser frequencies permits them to be utilized for a number of different purposes ranging from distance measuring to bathymetry and fluorosensing. Experiments continue in the development of laser fluorosensors; current investigations into the development of scanning laser imaging systems are encouraging. Both of these systems will be extremely valuable in the detection, identification, mapping and measurement of pollution discharges.

4.2.1.7 Active Gated Television (AGTV)

Operating Parameters

Active gated televisions combine the best qualities of low light level television and laser rangefinders. The LLLTV component of this combination sensor operates in the ultraviolet/visible/near infrared spectral regions. It has a night only capability under clear skies, with degradation occurring as the moisture content of the atmosphere increases.

Operational Considerations

The LLLTV has varying fields of view, and scans a designated area with a wide field of view, until a suspected target is located. At this instant a pulsed laser is activated to illuminate the target and the LLLTV changes its field of view, increasing the magnification power of the lens, to identify the target. By replacing the ranging laser with a laser having a frequency that activates fluorescence in pollutants, the system would be extremely valuable in the surveillance, under low light or dark conditions, of a large area surrounding a possible source of discharge.

However, in this type of operation, it would be necessary to have the laser scan at a pre-determined range within the LLLTV field of view, firing at intervals, to create detectable fluorescence in pollutants. Mapping of the aerial extent, determination of the type and measurement of the thickness (within certain limits) of the discharge, would be possible.

Imagery could be viewed in real time, with simultaneous recording of data on a VHS cassette recorder for replay and detailed examination at a later date. Other operating considerations are similar to those detailed for LLLTV systems in Section 4.2.1.2.

Mounting

Little difficulty would be encountered in mounting the modified AGTV system described above on a ground-based platform. General mounting instructions for photographic cameras as outlined in Section 4.2.1.1, and television cameras as described in Section 4.2.1.2 apply.

Level of Expertise

a) Operation - Considerable expertise would be required for an operator to recognize the fluorescent signature of a pollutant. It is suggested that this expertise could only be acquired through experience.

b) Interpretation - First phase interpretation would be automatically carried out by the operator in real-time. Detailed interpretation of data would require the expertise of an experienced analyst, in all probability, with the assistance of the operator.

Evaluation Summary

The modified AGTV system described above does not exist. It is included in this evaluation to show the potential for development of specialized equipment through the combination and/or modification of proven components. As envisioned, such a sensor would meet the requirements for a back-up system to FLIR - the only device currently available to provide wide area surveillance in total darkness. Other attributes include possible pollutant typing and thickness measurement capabilities.

4.2.1.8 Fraunhaufer Line Discriminator (FLD)

The Fraunhaufer Line Discriminator is strictly an experimental system, and serious difficulties have been encountered during the development phase. In its present state, it is not suitable for consideration as a candidate sensor for oil spill surveillance. However, in view of the fact that the system was investigated during the study, a brief description is presented for future reference.

The FLD is a passive device that senses in the ultraviolet, visible and near infrared spectral regions. In many respects the system is similar to a photometer, utilizing an upward looking incident radiation detector to provide data that is compared with information collected by a downward looking detector. Due to its extremely narrow atmospheric operating limitations, it does not have high potential for meeting requirements addressed in this study.

4.2.1.9 Passive Microwave

Operating Parameters

Passive microwave systems include both line-trace and point-source nonimaging devices and passive microwave imagers. They have a day/night capability and will operate under almost any type of weather conditions, with some dependency on the signal frequency chosen.

Operational Considerations

Commercial passive microwave systems for use in an airborne mode are readily available and have proven their ability to detect water-borne pollutants. Sufficient evidence exists to indicate a potential capability for the measurement of spill thickness. Unfortunately, test results were obtained from overflights of fairly large spills and insufficient data is available to assess the capabilities of passive microwave systems in the sensing of the small discharges under consideration. Considerable modification of existing systems will be required to adapt them for use on a ground-based platform. In view of the uncertainty regarding their capability to sense small, thin spills, and the probable high cost of carrying out required modifications, it is suggested that further research into both of these areas be carried out prior to making a firm commitment.

Mounting

As the size, shape, weight and configuration of a microwave system modified for ground-based use cannot be envisaged at this time, further discussion in this area would be redundant.

Level of Expertise

a) Operation - A fairly high level of expertise, and constant monitoring of outputs will be required if high quality, useful data is to be obtained.

b) Interpretation - Results comparable to that acquired with most types of airborne passive microwave systems will not require a high level of expertise to carry out first phase interpretation. However, as with returns from many types of sensors, final interpretation requiring reprocessing of data, and/or correlation with other data, will require the services of a fully trained interpreter.

Evaluation Summary

Passive microwave devices have an apparent high potential for all-weather sensing of chronic oil discharges. Existing systems will require considerable modification to adapt them to ground-based operation; the minimum size and thickness of pollutant discharges that can be sensed by such systems has not been firmly established. Further research is required.

4.2.1.10 Radar

On first consideration, active microwave systems called radar, appear to be the ideal instruments for the all-weather sensing of pollutant discharges. Airborne SLAR, SAR and scatterometers have proven their ability to detect and map large oil spills but, as with passive microwave systems, insufficient data is available to assess their ability to sense small, thin discharges. Active microwave systems also exist in the form of weather, search and marine radars. Weather and search radars are unsuitable due to their coarse resolution; marine radars are subject to interference from beam patterns and sea-clutter within approximately one mile of the antenna, and their normal output is unsuitable for pollutant recording.

SLAR and SAR systems require the forward motion of a platform to produce an image, and a side-looking mode is essential to their operation. If they could be adapted to ground-based operation by using a sweeping, or rotating antenna, their near-range returns would undoubtedly be subjected to the same degradation experienced with marine radars. Scatterometers provide the best possibility for successful operation in sensing chronic discharges, but modifications required to adapt them to operation from a ground-based platform would be excessive.

In view of other sensors available, the potential of passive microwave systems and the uncertainties existing regarding the capability of radars to sense very small discharges, it is suggested that they be given no further consideration, at this time.

4.2.1.11 Summary

In the preceding paragraphs, the use, or potential use, of sensors for monitoring visible, small chronic pollution discharges was discussed. Table 4.1 identifies

TABLE 4.1

POTENTIAL SENSORS FOR THE REMOTE SENSING OF VISIBLE CHRONIC DISCHARGE

Capability / Sensor	Proven, High Potential	Proven Not Suitable	Unproven Potential	New Technology Potential	Unsuitable	Remarks
Cameras		X*				
Television	X			X		Use of television in combination sensors
Radiometers		X		X		Recent developments show promise
Line Scanners		X		X		Use of electro-optical systems
FLIR	X			X		
Lasers	X			X		Development of imaging laser systems
AGTV			X	X		Variations on laser gating
FLD					X	
Microwave		X		X		
Radar					X	

* Not suitable for surveillance on a day-to-day operational basis, but provides the most permanent and useful record of events. Suitable as a back-up system.

the sensors and provides an indication of their existing capabilities. A sensor may have more than one entry in the capability column, providing there is a possible potential for upgrading the sensor through the application of new technology. Remarks are included for the clarification of specific entries.

4.2.2 Invisible Discharges

In the preceding sections, there has been extensive discussion regarding pollutant discharges that result in 50 or more parts per billion of pollutant in the water and are, therefore, capable of producing a visible sheen, or slick, on the water surface that may be detected using remote sensing methods. However, it is obvious that there must be discharges of petroleum pollutants resulting in much less than 50 parts per billion in the water, which are embodied into the water column, and do not leave a component on the surface that can be "seen" by the human eye, or other sensors. Hence the term "invisible" discharge, the second scenario examined in this study.

No documentation was identified in the literature review (Appendix B) regarding the ability of any remote sensing device to detect oil in the water column on an operational basis. Personal communication with experts in the field, revealed that some controversy exists regarding the requirement to detect invisible discharges. It is acknowledged that a certain amount of petroleum products, originating from natural seeps over many years, do exist in the water environment as a base-level background. The absorption of small quantities of chronic discharge pollutants, into the water column, may be a natural cleansing process that contributes minutely to this background. No sensor has been identified to date that can detect or measure this existing background level of pollutant, or the possible contribution made to the level, by small chronic discharge sources. However, it is possible that localized concentrations could become fairly high without being manifest as a visible sheen or slick, and hence, be a potential but undetected hazard to the surrounding environment.

For obvious reasons, most remote sensing devices may immediately be classified as unsuitable for the sensing of invisible chronic discharges. Only laser systems appear to have any potential for the detection of pollution in the water column. Laser bathymeters have a water penetration capability; laser fluorosensors may be used for identification of oil type. When combined with LLLTV and/or AGTV, laser systems may have new technology, but unproven potential, for the remote detection of invisible discharges. Table 4.2 presents sensor capability ratings in tabular form.

It is apparent that one of the first steps in future studies is to determine whether or not, invisible discharge pollutants do exist in a concentration that allows their detection and measurement. If remote sensing systems cannot be used to detect an invisible discharge, then immersion methods involving physical sampling of the

TABLE 4.2

POTENTIAL SENSORS FOR THE REMOTE SENSING OF INVISIBLE CHRONIC DISCHARGE

Capability Sensor	Proven, High Potential	Unproven Potential	New Technology Potential	Unsuitable in their present form	Remarks
Cameras				X	
Television			X	X	Use of television in combination sensors
Radiometers				X	
Line Scanners				X	
FLIR				X	
Lasers		X	X	X	Development of imaging lasers and improvement of present systems
AGTV			X	X	Variations in laser combinations
FLD				X	
Microwave				X	
Radar				X	

water should be assessed. It is important to determine if there is a potentially damaging concentration of pollutant incorporated into the water column.

SECTION 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 General

This report presents the findings of a study carried out to assess the adaptability of remote sensing systems to operate in a ground-based environment; the capabilities of remote sensing devices and techniques in the detection and monitoring of small, chronic pollutant discharges, on an operational basis. Conclusions presented in this section are based on information gleaned during an extensive literature search, discussions with numerous experts in related fields and the contractor's familiarity with the performance of various sensing devices. Recommendations are based on the premise that conclusions presented will be accepted as valid.

5.2 Conclusions

5.2.1 Visible Discharges

It is concluded that:

1. Photographic and television cameras are readily adaptable to operation on ground-based platforms and under clear atmospheric, good illumination conditions, will provide an operational capability for the detection and monitoring of chronic pollutant discharges.
2. Utilization of the relatively high-cost LLLTV cameras will extend this capability to sensing under clear atmosphere,

low-light conditions equivalent to one quarter moon illumination.

3. The capabilities of television cameras (including the LLLTV) can be greatly enhanced by combining them with a laser illuminating, and/or fluorescence inducing system.
4. FLIR systems are readily adaptable to ground-based operation, and provide a clear atmosphere day/night sensing capability.
5. Recent developments in the adaptation of infrared radiometers to the detection of methane gas leaks indicate that this type of radiometer, in the near future, may also be adapted to the sensing of chronic pollutant discharges.
6. There are no remote sensing devices, or combinations of sensors in existence that, in their present configuration, will provide an all-weather capability for the ground-based remote sensing of chronic pollution discharges.
7. Passive microwave sensing devices appear to have the highest potential for the lowest cost development of a ground-based, all-weather sensing system.
8. There are a number of other sensing devices under development that have some potential for application in the ground-based, chronic pollutant discharge remote sensing area.

5.2.2 Invisible Discharges

It is concluded that:

1. It may be impossible to detect invisible discharges by remote sensing methods.

2. Prior to further research into remote sensing methods, it will be necessary to determine the impact of invisible discharges on the environment.
3. Lasers operating in a spectral range that will penetrate water and/or create fluorescence, when combined with LLLTV or AGTV recording devices, have the highest potential for the detection of invisible pollutant discharges in the water column.

5.3 Recommendations

5.3.1 Visible Discharges

It is recommended that:

1. A laboratory test program be carried out on LLLTV and FLIR systems to determine the exact operating limitations of these sensors in the detection and monitoring of very small quantities of pollutant anticipated in a chronic discharge.
2. An examination of illuminating and fluorescence inducing lasers be carried out in conjunction with the above tests, to determine the combination of devices that provide the most efficient operational system, under the widest variety of operating conditions.
3. The selected system, or combination of devices be subjected to field trials, to determine if modifications and/or further development is required to adapt the system for operational use.

4. Current developments now being carried out in the use of infrared radiometers for the detection of methane gas leaks be closely monitored to determine their adaptability to the monitoring of chronic pollution discharges.
5. An investigation be carried out into the modifications required to adapt various types of passive microwave sensing devices to provide a ground-based, all-weather sensing capability.

5.3.2 Invisible Discharges

It is recommended that:

1. No further investigation into the use of remote sensing systems to detect and/or monitor invisible pollutant discharges be carried out until, using other methods such as immersion sensing, the base-line background level of existing pollutants has been measured; the effect of small invisible discharges, on this level has been determined.
2. If the above investigation indicates that there is a requirement to detect and monitor invisible discharges, a combination of LLLTV and laser devices be considered as prime candidates to be subjected to laboratory and/or field testing.

APPENDIX A

SCOPE OF WORK

SCOPE OF WORK

The principal objective of this study is to investigate existing remote sensing equipment and techniques that have a potential for adaptation as vessel or rig mounted systems capable of monitoring, on a routine basis, accidental or chronic oil or other waste discharges from drillsites and production facilities. The capabilities and limitations of each potentially suitable system will be documented and quantified to facilitate an evaluation of its ability to most efficiently meet the stated requirement under a wide variety of environmental conditions. Based on the findings of the evaluation procedures carried out, recommendations will be made as to the most appropriate system and technique that will provide, on an operational basis, information useful for countermeasures planning and possible future compliance monitoring.

To provide an orderly framework for the work, it has been broken down into six tasks as follows:

Task 1 - Literature and Information Search

- Conduct detailed literature search of

applicable documents, papers and reports contained within federal government, provincial government, university, and international libraries.

- Contact and/or visit Canadian federal, provincial and industrial agencies who are, or have been, involved in detection or mapping of oil spills, to discuss equipment and techniques utilized.

Task 2 - Documentation of Sensing Systems

- Identify and document existing, proven candidate systems and techniques, ranked in accordance with their probable capability to meet the requirement.
- Identify and document candidate systems or techniques that exist, but have not been proven, or are in the development stage.

Task 3 - Quantification of Systems

- Quantify each system and technique documented, in terms of its detection limits, sensing range, environmental restrictions, adaptability to rig or vessel mounting and operating limitations.
- Summarize results in a tabular form.

Task 4 - Evaluation of Sensors

- Develop and describe probable scenarios for accidental or chronic oil and production waste discharges.

- Evaluate the proven or theoretical performances of each system/technique within the context of developed scenarios.
- Tabulate results of the evaluation, with each system/technique categorized as to its potential i.e. most acceptable, potentially acceptable, unacceptable.

Task 5 - Recommendations

- Utilize results of the evaluation procedures carried out in task four to make fully justified recommendations, with each sensor, sensor combination and technique categorized as a) operational, b) theoretically usable but untested, and c) new technology with high potential.

Task 6 - Report Preparation

- Generate a report conforming to the required format and written in a style to facilitate accessibility to both specialist and non-specialist users of remote sensing technology.

APPENDIX B

ANNOTATED BIBLIOGRAPHY

ANNOTATED BIBLIOGRAPHY

An annotated bibliography of available literature relevant to the topic, "Chronic Oil Discharges", is presented. The publications vary in significance, but all present aspects important to the understanding of the technologies presented in the Chronic Oil Discharges study. The entries in the bibliography are arranged in alphabetical order.

A sample bibliographic entry is shown in Figure B1. This sample is annotated with numbers to help understand the material presented with each entry and to explain its organization. The notation on Figure B1 is described below:

1) Bibliographic entry - Contains - Name of Author(s) (Last name, Initials, for first author followed by Initials, last name for two or multiple authors), Month, Year of Publication, Title of Publication, Name of Journal, or Symposium Proceedings or Name of Agency or Company Name, Place or Address, Volume, Number, Page number or number of pages;
2) Affiliation of Author(s) at the Time of Publication;
3) Affiliation of Author(s) marked with corresponding symbol * or **. (This is only presented in the case of two or more authors and their affiliations are not the same);
4) Availability of the Publication - If the publication had CCRS, NTIS, or any other number which would help in its retrieval. (For example, the Publication on the Sample sheet can be obtained from CCRS);
5) Contains Author's Abstract or Introduction, or Summary. (The Author's Introduction or Summary is only provided in the case where the Publication does not contain the Author's Abstract. (These may be modified depending on their length);

6) Number of References in the Publication;
7) Identification of each Publication as Experimental, Theoretical, or General Review (combinations will be found) depending on its nature;
8) Reviewer's Evaluation - Highly Significant, Significant, or Normal;
9) Place of Data Collection for Works;
10) Date or Time of Data Collection;
11) System(s) under review or used for Data Collection - Name, Frequency, Wavelength, Polarization, etc. used;
12) Key Words; and
13) Reviewer's Comments (or Author's Conclusions or Summary (possibly modified) from the Publication, not included in the abstract.

The above notations will be included only if they are available and/or applicable.

① O'Neil, R.A., L. Buja-Bijunas and D.M. Rayner*, (March 1980), "Field Performance of a laser fluorosensor for the detection of oil spills", Applied Optics, Vol. 19, No. 6, pp. 863-870.
② → Canada Centre for Remote Sensing, Ottawa, Ontario; National Research Council, Ottawa, Ontario*. CCRS # 1022671. ← ④
③

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⑤ Abstract - An airborne laser fluorosensor is described that was designed to detect and identify targets by means of the characteristic fluorescence emission spectrum. The first field trials of the sensor over marine oil and dye spills are reported. A correlation technique has been developed that, when applied to the data collected during these field trials, clearly differentiated among dye, the two crude oils, and the general fluorescence background of ocean water.

⑦

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⑥ → Ten, General Review, Highly Significant. ← ⑧
⑨ → New Jersey Coast; 1978. ← ⑩
⑪ → Laser Fluorosensor (337 nm).
⑫ Remote sensing, Detection, Oil spill, Laser fluorosensor, Fluorescence.

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⑬ Comments - The field trials showed the laser fluorosensor capable of detecting oil in a marine environment. This paper dealt exclusively with the detection of oil by the fluorosensor. This sensor will continue to be tested over oil spills, where the authors predict that it will do better than identifying oil by proving capable of classifying oils as light, crude or heavy.

FIGURE B-I SAMPLE ENTRY

Abramov, O.I., V.I. Yeremin, L.I. Lobov and V.V. Polovinko,
(1977), "Use of Lidar to Detect Oil Pollution of the Sea
Surface", Atmospheric and Ocean Physics, IZV., Vol. 13,
No. 3, pp. 232-234. CCRS # 1018819.

Introduction (Modified) - Of the possible laser methods of investigating pollution on the basis of analysis of the energy, polarization, and spectral characteristics of radiation from the sea, we shall consider the last, which makes use of spectroscopic procedures. The spectral composition of the sea return (SR) on directional beaming with an ultraviolet laser is analyzed in this method.

Five, General Review, Significant.

Remote sensing, Oil pollution, Detection, Lidar, Lasers,
Environmental pollution.

Author's Conclusions - 1. The results of the experimental studies indicated the possibility of detecting petroleum product zones on the surface of the sea and determining their thickness by remote sounding of the water with a powerful pulsed laser at λ= 0.3472 m.

2. Remote sounding of the sea with a high-powered pulsed laser at λ= 0.3472 m offers a tool for study not only of oil pollution of the sea surface, but also of the layer within the propagation range of the ultraviolet light.

3. The SR spectra obtained by the remote method can be used to study the parameters of the sea water that govern the mechanisms of SR formation.

4. The set of instruments used in the experiment, which was developed at the V.I. Lenin All-Union Electrical Engineering Institute, demonstrated the possibility of operating such opticoelectronic units on ships in the open sea.

Anonymous, (January 1971), "LLLTV - A Trend Towards Silicon", Electro-Optical Systems Design, pp. 16-19. CCRS # 1001109.

Abstract - A year ago the silicon-target camera tube was in the developmental stages and promising more than it could deliver. It has now become a production reality and a serious competitor for the LLLTV dollar.

Nil, General Review, Normal.
Low Light Level Television.
Remote sensing, LLLTV.

Author's Conclusions - The development of silicon-target imaging devices has been a boon to the system designer. He now has many different devices from which to select and thus can optimize a particular design. The result should be good for the LLLTV technology and result in more widespread usage.

Axelsson, S. and F. Ohlsson, (1972), "The Remote Sensing of Oil Slicks", Ambio, Sweden, Vol. 2, No. 1, pp. 70-76. CCRS # 1004290.

Abstract - The frequent marine oil spills point out the need for effective methods of oil slick detection and surveillance. The most efficient means for localizing a spill and measuring its extent is the use of airborne remote sensing systems. In this report the fundamental relation between the remote sensing signal and oil slick characteristics is investigated. The discussion is based upon results from a study for the Swedish Board for Technical Development.

Due to differences between the material properties of oil and water, an oil slick is detectable in most wavelength bands. The capability of mapping thin oil slicks varies with the wavelength used. The amount of cloud cover also has a great influence on the contrast and the optimum wavelength band for mapping. A significant relation also exists between the contrast and the thickness of the oil film in some parts of the spectrum, particularly in the green band, thermal infrared (IR) and the microwave region. The multiband signature is also related to the oil type.

The main interpretation problem is that the oil signature is also influenced by environmental parameters like amount of cloud cover, sea-state, wind speed, water quality and attenuation and scattering of the atmosphere. The accuracy of the interpretation is highly improved if information about these parameters is available. Particularly the thickness mapping can be performed more efficiently if it is possible to calibrate the interpretation model by thickness values from a few points of the slick. The quality of the extracted data about the oil slick is also enhanced if information from different wavelength bands is combined. If microwave sensors are included, the system can also operate during all weather conditions.

Sixteen, Theoretical and Experimental, Significant.
Baltic Sea, September 1972.
Remote sensing, Oil pollution, Oil slick, Ultraviolet, Visible, Thermal IR, Microwave, oil slick spreading.

Comments - On a theoretical basis, the possibilities and limitations of remote sensing for oil pollution mapping were studied. The interaction between the remote sensing signature and the oil slick were analyzed, focusing on the contrast between the oil slick and water in relation to oil type and film thickness. The study was concerned mainly with optical sensors but sensors operating in the microwave band were also included.

Backlund, L., (1979), "Airborne Oil Spill Surveillance Systems in Sweden", Proceedings from the 1979 Oil Spill Conference, Los Angeles, California, pp. 305-311. Swedish Space Corporation, Solna, Sweden.

Abstract - Two different oil spill surveillance systems have been developed by the Swedish Space Corporation for the Swedish Coast Guard and the Swedish Board for Space Activities. These systems are installed in two Coast Guard Cessna 337 aircraft. One of the systems is based on a side looking airborne radar, developed by L.M. Ericsson Telephone Company under contract to the SSC, and the other on a Daedalus infrared/ultraviolet line scanner. Both systems generate real-time imagery on a television monitor. In addition to the remote-sensing equipment, both aircraft have a Decca tactical air navigational system and a camera system on board. The technical evaluation and field testing of the two surveillance systems was carried out during 1978. The systems gradually will be put into operational use by the Swedish Coast Guard for coastal surveillance.

Six, Experimental and General Review, Significant.
Camera system, SLAR, IR/UV Line Scanner.
Oil spills, Remote sensing, Surveillance, Sweden.

Comments - Three basic systems are operational on the Swedish Surveillance system, including; a camera system, a side looking airborne radar and a IR/UV line scanner. All three systems are reviewed and their basic designs are discussed. The prototype system was tested in the late 1970's. Potential future improvements are outlined.

Bentz, A.P., (1980), "Oil Spill Identification and Remote Sensing", American Chemical Society, No. 185, pp. 55-86. United States Research and Development Center, Avery Point, Groton, Connecticut. SRLA # 270,127; CCRS # 1030496.

Abstract - This chapter is comprised of two distinct parts. The first is a review of the state of the art oil spill identification techniques. It includes significant developments that have firmly established oil fingerprinting as a valid approach to identification of oil spill sources. These include: increased understanding of weathering phenomena, refinement of analytical techniques and pattern recognition techniques for oil comparison, adoption by ASTM of new standard methods for spill identification, establishment of a Central Oil Identification Laboratory (COIL) and satellite Field Oil Identification Laboratories (FOIL) by the U.S. Coast Guard, and four successful tests of the analytical methodology in court. The second part of this chapter is a brief account of development of planned and operational remote sensing systems as applied to oil spill detection, identification and mapping.

One hundred and six, General Review, Normal.
Oil spills, Remote sensing, Detection, Identification, Legal.

Author's Summary - The chapter presents some of the significant recent developments and indicates the direction of future developments in oil spill fingerprinting and remote sensing. Widespread adoption of uniform practices in oil identification will benefit all who are concerned with the problem of identifying sources of oil pollution. Airborne remote sensing is, at present, the only practical way to maintain pollution surveillance over wide areas of open sea.

Bespalova, E.A., Y.A. Militskii, I.V. Pokrouskaya, U.G. Mirovskii, M.D. Raev, E.A. Sharkov and V.S. Etkin, (1978), "Spectral Characteristics of Thermal Radio Emission from a Sea Surface Polluted by Petroleum Products", Meteorologiya i Gidrologiya, No. 10, pp. 71-77. CCRS # 1026739.

Abstract - Experimental results from multichannel radiothermal studies of the radio emission from oil spills on the sea surface that were made under various hydrometeorological conditions are reported. Two effects were observed in the interaction of the waves and oil films: positive variations in light waves and negative variations in heavy waves. The spectral characteristics obtained for these variations in the range 0.8 - 3.2 cm permitted certain inferences as to the physical causes of these effects.

Ten, Experimental, Significant.

Caspian Sea; November 1976.

Multichannel radiometer.

Remote sensing, Oil spills, Pollution, Petroleum products, Thermal emission.

Author's Conclusions - This multichannel radiothermal investigation of oil pollution in the region of Neftyanye Kamni distinctly revealed two effects in the interaction of undeveloped (nonstationary) waves and petroleum-product films, one of which (the positive variations) is physically related to matching of the wave resistances of the two half-spaces (air and water) by the oil film, while the second (the negative variations) arises because the oil film suppresses strong waves, drop-and-spray clouds, and foaming activity.

With the highly sensitive multichannel passive apparatus we were able to bring out spectral features in various regions of the radiothermal field of the polluted water surface, and this, in turn, makes possible certain inferences as to the physical causes of the observed effects.

Bressel, C., I. Itzkan, J.E. Nunes and F. Hoge*, (April 1977), "Airborne Oceanographic Lidar System", Proceedings of the Eighth International Symposium on Remote Sensing of Environment, Vol. II, ERIM, pp. 1259-1267. Avco Everett Research Laboratory, Inc., Everett, Massachusetts; NASA Wallops Flight Center, Wallops Island, Virginia*. CCRS # 1014331.

Abstract - This paper acquaints the technical community with the characteristics of an Airborne Oceanographic Lidar (AOL) developed for NASA by AERL, Inc. We describe the AOL system, discuss its potential for various measurement applications including bathymetry and fluorosensing, and invite interested investigators to become users.

Nil, General Review, Normal.

Airborne Oceanographic Lidar System (AOL).

Remote sensing, Airborne, Lidar, Oceanography.

Comments - This short paper discusses the operating characteristics of the AOL system and includes potential applications of the system in both the bathymetric and fluorosensing modes.

Bristow, M.P.F., W.R. Houston* and R.M. Measures*, (September 1973), "Development of a Laser Fluorosensor for Airborne Surveying of the Aquatic Environment", Proceedings of the Use of Lasers for Hydrographic Studies, pp. 119-136. Canada Centre for Remote Sensing, Ottawa, Ontario; University of Toronto, Toronto, Ontario*.

Abstract - A field based laser fluorosensor, employing a pulsed nitrogen laser and telescope-photomultiplier detector system, has been successfully tested at night from a cliff top site overlooking Lake Ontario providing target ranges greater than 274 meters (900 feet). Remotely sensed spectra and amplitude changes in the fluorescence emission of natural waters have shown potential as a water quality indicator. In this connection, a convenient internal reference standard with which to gauge the amplitude of the fluorescence signal is realized in the form of the concurrent water Raman emission. Remote measurements of oil fluorescence emission spectra suggest that airborne laser fluorosensors are capable of detecting and characterizing the oil in a given slick and that environmental aging of these slicks does not significantly alter their fluorescence emission signature. This system has now been modified for airborne operations with a view to the eventual development of a compact lightweight emission scanning laser fluorosensor.

Six, General Review, Significant.

Scarborough Bluffs, Lake Ontario.

Laser Fluorosensor.

Remote sensing, Laser fluorosensor, Fluorescence, Lake Ontario, Aquatic environment.

Author's Conclusions (Modified) - Promising results have been obtained, suggesting that the laser fluorosensor has the ability to remotely detect and record the spectral fluorescence characteristics of natural and polluted waters. To date, the laser fluorosensor is the only remote sensing device which has demonstrated an ability to detect and characterize an oil spill.

It is essential that an oil spill be characterized in such a manner that its identity can be directly related to that of a sample removed from the suspect ship, and then used as legal evidence. Remotely sensed fluorescence excitation or emission spectra appear to provide the information needed to constitute a characteristic signature suitable for use as prosecution evidence.

Brunsveld Van Hulten, H.W., (1979), "Remote Sensing Program for Oil Detection in the Netherlands", Proceedings of the Airborne Remote Sensing of Oil Spills in Coastal Waters, Washington, D.C., 3 pages. Rijkswaterstaat, The Hague, The Netherlands.

Introduction (Modified) - To aid in the task of surveilling the Dutch continental shelf, RIJKSWATERSTAAT (Department of water control) investigates remote sensing techniques as a possible surveillance system. To build up techniques for adequately handling the vast amount of data inevitably produced by such activities, a research program was started in 1971, supported by the Physics Laboratory (TNO) and the National Aerospace Laboratory (NLR). Emphasis was laid on sensor-object interaction studies. The initial sensor was an infrared line scanner (IRLS), followed in 1974 by an X band Side Looking Radar (SLAR) of the real aperture type with horizontal polarization and a large footprint carried on a QUEEN AIR BEECHCRAFT from NLR. Because of the limited size and payload of the aircraft, both sensors cannot be flown simultaneously. Only conventional cameras and an inertial navigation system can be flown with the SLAR and the IRLS. Of primary importance was the use of SLAR to measure contrast produced by waves and oil spills.

Nil, Experimental and General Review, Normal.

Platform Noordwijk; 1977, and the North Sea; 1975.

SLAR, Scatterometer, Thermal IR, Line Scanner.

Remote sensing, Oil spills, Oil detection, Surveillance, SLAR, Thermal IR, Sensors, The Netherlands.

Comments - This paper reviews the experiments, results and conclusions of The Netherlands investigations into the use of a remote sensing system for oil spill detection, wave monitoring and traffic density.

Burkhalter, R. and C.L. Meyer, (1979), "The Operational Oil Pollution Surveillance System Being Used in France", Proceedings of the Airborne Remote Sensing of Oil Spills in Coastal Waters, Washington, D.C., 9 pages. Laboratoire National d'Essais, Paris, France.

Introduction (Modified) - The long and varied coastline of France bordering three sea areas of very different character gives rise to a considerable diversity in the nature and relative importance of the resources. The highest risk of tanker accidents and deliberate oil spills exists, mainly at the approaches to the major oil terminals and in the channel between France and the south coast of England. This area is one of the most congested waterways of the world and a number of serious accidents have confirmed the fact that the channel is one of the highest risk zones for collisions and groundings and one of the most polluted areas, along the French coast by deliberate discharges.

Therefore, the Merchant Navy has been entrusted with purchasing a remote sensing system corresponding to the results of research carried out in this field.

Nil, General Review, Normal.

IR Line Scanner, Cameras.

Remote sensing, France, Oil spills, Surveillance, Infrared Line Scanner.

Comments - An explanation of the French remote surveillance system, the sensors carried aboard, the system's performance and operational limits, as well as developments necessary, are all discussed in the context of this article.

Catoe, C.E., (March 1973), "Remote Sensing Techniques for Detecting Oil Slicks", Journal of Petroleum Technology, pp. 267-278. NASA. CCRS # 1004284.

Introduction (Modified) - There are a variety of devices for "seeing" oil on water - sensors that make use of both spatial and spectral dimensions. All of the devices are limited to a greater or lesser degree, but all are also considerably more reliable than the naked human eye.

We shall consider here the signature properties of oil slicks that make them amenable to remote sensing. We shall give particular attention to those signature properties of oil slicks that are useful in (1) detecting oil films on water surface, (2) mapping the areal extent of the slicks, (3) measuring the thickness of the slicks, and (4) identifying oil types.

Thirteen, General Review, Significant.

NRL four-frequency dual-channel radar system, Aerojet-General Corporation 0.81 cm radiometer.

Remote sensing, Detection, Oil spill, Microwave, Radar.

Author's Conclusions (Modified) - An analysis of the signature properties of oil from the ultraviolet to radar region indicates that it is possible to detect oil films, oil slicks, and oil layers on water surfaces by remote sensing techniques.

In the ultraviolet region, the reflective signature and its fluorescent signature are the basic mechanisms for detecting oil. In the visible region, the reflective signature of oil is the primary mechanism for oil detection occurring near the ultraviolet and red part of the spectrum.

In the near infrared, the reflective signature of oil is used for detection, whereas in the far infrared, the thermal signature of oil is important.

The microwave signature of oil is dependent on the emissivity of the oil and the wave structure modification, whereas in the radar region, the wave structure modification in terms of capillary wave suppression that reduces the radar backscatter cross-section, is important for oil detection.

Of the imaging techniques considered, ultraviolet photography is considered to have great potential for detecting oil. Panchromatic, infrared and colour photography do not lend themselves well to resolving the extent of an oil slick.

The optical-mechanism scanners (MSS and IR imagers) are effective in detecting and mapping oil slicks if operated in the UV, blue, red and 8 to 14 m portions of the spectrum.

Radar and passive microwave techniques appear promising and show the best potential for providing adverse-weather coverage of large areas on a 24 hour basis, but will be affected by sea-state.

Additional research must be devoted to determining oil thickness and to identifying oil types.

Catoe, C.E. and J.T. McLean, (1979), "A Multispectral Look at Oil Pollution, Detection, Monitoring and Law Enforcement", Reference Incomplete; Contact CCRS. CCRS # 1019756.

Introduction (Modified) - Oil spills and subsequent environmental problems are a major international concern.

In order to reduce the threat of oil pollution in the United States, attention has been focused on developing regulations, methods and procedures to reduce the probability of oil spillage. It is reasonable to assume that there will still be oil spills, that will not be reported in a timely manner. What is needed to combat these unreported incidents are effective techniques for the remote detection and surveillance of oil slicks, in sufficient time, so that adequate countermeasures can be utilized.

There are a variety of devices for "seeing" oil on water. What is required is a multispectral approach to resolve the problems of: 1) Detecting oil films on water 2) Mapping the areal extent of the slick 3) Measuring slick thickness 4) Identifying oil types.

In this paper, a multispectral look at oil pollution, detection, monitoring, and law enforcement capabilities will be considered.

Twenty seven, General Review, Highly Significant.

Oil pollution, Oil spills, Detection, Monitoring, Law enforcement, Multispectral, Microwave, Radar, Signatures, Remote sensing.

Comments - Signature characteristics of oil in the Ultraviolet, Visible, Infrared and Microwave regions, as well as, the signatures of oil for various sensors are discussed. Operational Constraints and Law Enforcement Requirements are also reviewed.

Centre for Cold Ocean Resources Engineering (C-CORE),
(September 1981), "Microwave Systems for Detecting Oil
Slicks in Ice-Infested Waters: Phase I - Literature
Review and Feasibility Study", Environmental Protection
Service, Environment Canada, Ottawa, Ontario, 356 pages.
Report EPS 3-EC-81-3.

Abstract - A study was undertaken to ascertain the possibilities and problems associated with the use of microwave techniques in detecting oil pollution in the ice environment. A comprehensive investigation into the microwave emission and scattering properties of sea ice, oil on water, and the ocean surface was made and the results of analyses are presented. Available information on the electrical properties of oil and the behaviour of oil in the ice environment is included. A selected, annotated bibliography of the published literature on microwave scattering and emission from sea ice, water and oil on the water surface is attached as Appendix 6. The design and data requirements of an experiment have been outlined. Possible radar data processing and analyses methods are given. In recommending required future efforts, it is suggested that theoretical and laboratory studies, as well as experiments under controlled conditions, are likely to produce quantitative information on the microwave emission and scattering from oil in the ice environment.

The results show that only a qualitative assessment of a limited nature can be made on the performance of active and passive microwave systems in detecting oil slicks in the ice environment from the limited information available on microwave emission and scattering from sea ice, oil on water, and the ocean.

It appears that either Ku- or X-band active measurements, along with L-band measurements, are suitable for

detecting oil when it is present on and in the top surface of the ice. Both VV and HH polarizations seem equally likely to succeed, with cross-polarization providing additional useful information.

The passive systems operating at frequencies of around 37 GHz with horizontal polarization and at angles of incidence of 30° to 45° from nadir seem appropriate. The use of a lower frequency in the range from 8 to 14 GHz may provide additional information.

Active and passive systems operating in the frequency range from 100 to 300 MHz may be able to detect oil when it is present under ice, or is contained within the lower regions of sea ice.

The presence of oil in the ice environment is likely to be detected through indirect subtle clues (i.e., changes in texture and tone such as those produced by increased melting of oil covered areas in comparison with oil free areas).

Sixteen, General Review, Highly Significant.

Remote sensing, Detection, Oil slicks, Pollution, Ice-infested waters, Microwave, Bibliography.

Author's Summary - The microwave scattering and emission characteristics of water, ice and oil over water were investigated on the basis of available literature, and detailed results are presented in the appendices. Summaries of the behaviour of oil in the ice environment and the electrical properties of oil are also included. An annotated bibliography of the published literature available on the microwave scattering and emission properties of oil, water, and ice was compiled and provided in Appendix 6.

It should be pointed out that whatever radar and radiometer data are available are of limited use because of the nonavailability of corroborative "ground truth" information. Moreover, most of the data had been gathered with uncalibrated systems which makes the task of evaluation and comparison difficult.

This report contains six appendices each including significant conclusions, recommendations and references.

Appendix 1 - Oil in an Ice Environment
Appendix 2 - Electrical Properties of Oil
Appendix 3 - Microwave Emission and Scattering from the Ocean
Appendix 4 - Microwave Backscatter and Emission from Sea Ice
Appendix 5 - Microwave Emission and Backscatter from Oil on Water
Appendix 6 - Annotated Bibliography - 89 references.

Chimels, V. and N.P. Krut, (1975), "Thermal Imaging Sensors Evaluation and Measurement Techniques", NAECON '75 Record, pp. 583-588. Air Force Avionics Lab, Wright-Patterson Air Force Base, Ohio. CCRS # 1008930.

Abstract - This paper discusses methods and techniques used in the test and evaluation of thermal imaging sensors. Techniques used include square wave response and Fourier transform methods. From the standpoint of sensor performance, the three most important parameters are modulation transfer function, signal transfer function, and minimum resolvable temperature. These parameters are used to describe the imaging quality of the sensor. Secondary parameters measured are resolvable temperature, noise equivalent temperature, field of view, magnification, and distortion. Test data and experimental results are presented and discussed.

Nil, General Review, Normal.
Thermal Imaging Systems.
Remote sensing, Sensors, Thermal imaging, Measurement techniques.

Author's Summary - The procedures described represent the most current techniques in the evaluation of thermal imaging sensors. These procedures are not unique, having been patterned after testing procedures pioneered at Night Vision Laboratories and Texas Instruments, Incorporated. The procedures described for signal transfer function and spectral response are different from those used at other laboratories because they have been updated to incorporate changes suggested by the JTCG-TIS. These procedures have proven successful in the test and evaluation of thermal imaging sensors and are the basis of all measurements performed at the Air Force Avionics Laboratory.

Croswell, W.F., (January 1980), "Assessment of the Use of Space Technology in the Monitoring of Oil Spills and Ocean Pollution", NASA, Langley Research Center, Hampton, Virginia, 459 pages. CCRS # 1023395-1023405.

Introduction (Modified) - In 1978 the United States Congress directed the National Aeronautics and Space Administration to investigate the utility of satellite systems and space technology in the detection and monitoring of oceanic oil spills and waste pollution. NASA's program in response to this directive has included the management of the study that is the subject of this report.

The study addressed the following basic goals that are pertinent to an assessment of the potential of space systems and technology in this important application:

- Determination of the measurement requirements and the end products required by other agencies who are assigned operational responsibilities.
- Assessment of the present state-of-the-art, adequacy of the current technology, and the advances in technology needed to meet the requirements.
- Definition of the characteristics of a future satellite system that would meet the requirements.

One hundred and fifty nine, General Review, Significant.
Remote sensing, Oil spills, Pollution, Space technology, Monitoring, Detection.

Comments - An initial technology base exists for space monitoring of oil spills and waste pollutants. A comparative analysis examined six alternative systems concepts and ranked them using criteria such as cost, coverage capabilities, and timeliness of the information. The option exhibiting the highest rating utilizes NOSS and the spacecraft for ICEX as the primary space platforms. The latter would contain wide swath pointable SAR and pointable Optical Linear Array with 100 meters resolution. The pointable feature was found to be very useful in providing the desired coastal coverage. An important element of the system is the centralized Data Processing System which permits data from many sources to be processed and disseminated to the users.

Croswell, W.F., H. Blume and J.W. Johnson, (June 1981),
"Microwave Remote Sensing Measurements of Oil Pollution on
the Ocean", In: Geoscience and Remote Sensing Symposium
16ARSS '81, Vol. 2, pp. 1246-1251. NASA Langley Research
Center, Hampton, VA. CCRS # 1035110.

Abstract - A series of experiments have been performed at sea during which an array of microwave and optical remote sensors were flown in aircraft over fresh and weathered crude oil released from a surface research vessel. In another experiment a slick was formed on the sea by release of frozen olexl(alcohol cubes) from a helicopter. For the crude oil experiments microwave radiometric measurements at 1.43 GHz, 2.65 GHz, 22 GHz and 31 GHz are reported along with variable incidence angle scattering measurements at 13.9 GHz. For these experiments unusual depressions in the L-band brightness temperature were observed, possibly related to dispersants applied to the crude oil. Similar depressions, but with much larger values, were observed over the olexl alcohol monomolecular slicks. Measurements at 22 and 31 GHz over identical crude oils, with or without dispersants revealed expected increases in brightness temperature of the oil covered sea. The 31 and 22 GHz images were used to infer oil volume, yielding values which bound the known amount spilled. Ku band scattering measurements were obtained in repeated passes over crude oil slicks both with and without dispersant applied. The scattering results obtained were unexpected based on published data. First, strong cross section changes occurred as a function of incidence angle with the maximum effect due to the oil films in the 25^{o} - 35^{o} incidence angle region. This is in direct contrast to the commonly held assumption that large incidence angles (shallow depression angles) are preferred for imaging oil on the sea. Furthermore, the notion that VV polarization as preferred from a signal-to-noise ratio

standpoint is weak at 30° incidence angle since the difference in scattering coefficient (HH vs VV) goes to zero at nadir.

One, Experimental, Significant.
1978-1979.
22 and 31 GHz Radiometer, L-S Band Radiometer and Ku Band Radar.

Comments - The abstract for this paper contains a full description of the paper's contents and results.

Croswell, W.F., J.C. Fedors, F.E. Hoge*, R.N. Swift** and J.C. Johnson***, (January 1983), "Ocean Experiments and Remotely Sensed Images of Chemically Dispersed Oil Spills", IEEE Transactions on Geoscience and Remote Sensing, Vol. GE-21, No.1, pp. 2-15. NASA, Langley Research Center, Hampton, VA.; NASA, Goddard Space Flight Center, Wallops Island, VA*.; EG&G Washington Analytical Service Center, Inc., Pocomoke, MD.**; J.B.F. Scientific Corporation, Wilmington, MD.***. CCRS # 1038899.

Abstract - A series of experiments was performed at sea where the effectiveness of dispersants applied from a helicopter was tested on fresh and weathered crude oils released from a surface research vessel. In conjunction with these experiments, remote sensing measurements using an array of airborne optical and microwave sensors were performed in order to aid in the interpretation of the dispersant effectiveness and to obtain quantitative images of oil on the sea under controlled conditions. Surface oil thickness and volume are inferred from airborne measurements using a dual-channel microwave imaging radiometer, aerial color photography, and an airborne oceanographic lidar. The remotely sensed measurements are compared with point sampled data obtained using a research vessel.

The mass balance computations of surface versus subsurface oil volume using remotely sensed and point sampled data are consistent with each other and with the volumes of oil released. Data collected by the several techniques concur in indicating that, for the oils used and under the sea conditions encountered, the dispersant and application method are primarily useful when applied to fresh oil.

Twenty eight, Experimental and General Review, Significant.

East Coast of U.S.; 1978.

Four aircraft - 20 different sensors.

Remote sensing, Oil spills, Sensors, Experimental.

Author's Conclusions (Modified) - This multidisciplinary effort has provided information about the effects of chemical dispersants on spilled oil and has demonstrated the potential for remotely detecting and monitoring spilled oil.

Data obtained from the sensors as well as the in situ samples indicated rather consistently the effects resulting from the treatment of the crude oils with dispersant. Infrared photographs and airborne laser images delineated the boundaries of the outer slick region and provided insight into the spreading characteristics of the oil under various experimental conditions. The lidar also was able to yield thickness distributions for the thinner slick regions that are potentially useful in the understanding of fractionation processes in the dissipating slicks. The microwave effectively delineated and quantified the surface portion of the oil in the thicker region near the head of the slick and permitted valuable estimates of the behaviour of the lenses throughout the experiments.

Cuny, J.J., C.B. Johnson and T.F. Lynch, (1979), "Proximity focused image tube intensified charge injection device (CID) camera for low light level television", Society of Photo-optical Instrumentation Engineers, Vol. 203, 5 pages. ITT Electro-Optical Products Division, Fort Wayne, Indiana. CCRS # 1022783.

Abstract - A complete intensified television camera has been developed using an intensified CID in conjunction with a standard camera control. The camera has been made in two versions, one for intermediate to low light levels and one for low light levels. In both cases the camera uses proximity focused tubes. The range of the camera has been extended four orders of magnitude with only a 20% loss in maximum resolution over the unintensified version. These intensifiers have been specially modified for use in these cameras. As a result, threshold imaging has been achieved at 10^{-7} foot candles incident on the face plate of the tube with the camera operating at standard TV scan rates.

The camera head can be kept as small as 3.6 in x 3.1 in x 3.0 in and weigh less than one pound.

Selection of the photocathode allows the camera to have sensitivity from the UV to the near IR and allow for fast gating of the camera to less than 5 nsec, if necessary.

Both camera designs are discussed with respect to performance and design.

Four, General Review, Significant.

Comments - This paper describes the results of combining the optical intensified array into the camera thus having a low light level system capable of several unique methods of operation and application.

Deekshatulu, B.L. and O.P. Bajpai, (December 1982), "Physics of Remote Sensing", Current Science, Vol. 51, No. 24, pp. 1132-1143. National Remote Sensing Agency, India, CCRS # 1038693.

Introduction (Modified) - Remote sensing is the science of deriving information about an object for measurements made at a distance from the object without actually coming in contact with it. Sensors and techniques used have improved our capability to gather information about the earth's natural resources and environment.

This report begins with giving illustrations of the typical spectral signatures of earth features and effects of the physical, biological processes on the spectral signatures followed by a brief discussion on the effects of atmosphere on remote sensing and possible ways of correcting them. The instrumentation for multispectral remote sensing are also discussed followed by a brief mention of the applications of remote sensing to various disciplines. The discussion will be limited to the optical region of the EM spectrum i.e. 0.3 to 15 μm which is the most exploited spectral region for remote sensing.

Fourteen, General Review, Normal.
Remote sensing, Physics, Electromagnetic spectrum.

Comments - Good general discussion, overview of the basics of remote sensing.

DeLoor, P.G. and P. Hoogeboom, (January 1982), "A Discrepancy Between Ground-Based and Airborne Radar Backscatter Measurements", IEEE Transactions on Geo-Science and Remote Sensing, Vol. GE-20, No. 1. Physics Laboratory, TNO, The Hague, The Netherlands. CCRS # 1033112.

Abstract - A difference is observed between the radar backscatter data of the sea obtained with airborne and ground-based systems. Seen the consistency within the respective measurements this difference is most probably a systematic one and independent of the measuring system.

Nine, Experimental, Significant.

Noordwijk, 11 km from Dutch coast in the North Sea.
1977, 1978, 1979.

Remote sensing, Radar.

Comments - An X-band radar was installed on the platform Noordwijk and measurements were made from both this platform and from the air. The discrepancies in the measurements between these two methods are given and the possible reasons for the variations are discussed.

de Villiers, J.N., (September 1973), "Airborne Detection and Mapping of Oil Spills, Grand Bahamas, February 1973", Canada Centre for Remote Sensing, Ottawa, Ontario, 14 pages. Canada Centre for Remote Sensing, Ottawa, Ontario. CCRS # 1005299.

Abstract - An airborne exercise is described employing various sensors to investigate their ability to detect and map Louisiana Crude and Naptha oil spills, both by day and by night.

It has shown that photographic, infra-red scanning and low light level T.V. all have some ability to detect Louisiana; only infra-red scanning detected naptha. None of these sensors could identify the anomalies as oil.

A laser fluorosensor showed promise in detecting oil at night. Further development will be needed to explore the full potential of such a technique.

Nil, General Review, Highly Significant.

Grand Bahamas; February 1973.

Multiband cameras, IR Line Scanner, Closed-circuit Television System, LLLTV and a Laser Fluorosensor.

Remote sensing, Oil spills, Grand Bahamas, Detection, Mapping, Sensors.

Author's Conclusions (Modified) - During the day, crude oil is easily detected and mapped in the early stages of a spill with good colour aerial photography. Contrary to the results of others, the ultra-violet imagery gave little information.

Colour photographic data can be interpreted as oil fairly readily during the early stages of a spill. All the other forms of data, with the possible exception of the fluorosensor, show up "anomalies" which may or may not be oil.

The closed circuit TV imagery, whilst detecting the oil, is never as good as the photographic data. The Barnes radiation thermometer is useful for measuring the contrast ratios of oil on water in the thermal infra-red; otherwise it is inferior to the thermal infra-red scanners in detecting oil.

Thermal infra-red scanning is excellent for detecting the "bottoms" and thicker parts of the spill, but the thin tail is not very discernible.

Very light fuel oils (e.g. naptha) cannot be detected by photographic sensors. Thermal infra-red scanning does detect naptha type oils.

At night, thermal infra-red scanning not unnaturally provides the same detection capability as during the day. Low light level television can also detect crude oil at night. The laser fluorosensing technique shows great promise.

de Villiers, N. and M. Bristow, (November 1973), "On the Relative Merits of Using Either CW Helium-Cadmium or Pulsed Nitrogen Lasers as the Fluorescence Excitation Source in Airborne Laser Fluorosensing System", Canada Centre for Remote Sensing, Ottawa, Ontario, 5 pages. Canada Centre for Remote Sensing. Technical Note 73-6.

Abstract - The relative merits of using either low power CW or high power pulsed lasers as the excitation source in airborne laser-fluorosensing systems are discussed. Using performance data for commercially available lasers, it is shown that for most airborne applications, pulsed nitrogen lasers provide significant advantages over CW He-Cd lasers.

One, General Review, Significant.
A C.W. Helium-Cadmium Laser and a Pulsed Nitrogen Laser.
Remote sensing, Fluorescence, Excitation, Lasers, Fluorosensing.

Comments - The CW Helium-Cadmium and Pulsed Nitrogen Lasers are compared with reference to their operating characteristics and performance.

Edgerton, A.T., J.J. Bommarito, R.S. Schwantje and D.C. Meeks, (May 1975), "Development of a Prototype Oil Surveillance System, Final Report", DOT-USCG, Washington, D.C., 311 pages. Aerojet ElectroSystems Company, Azusa, California. CCRS # 106733 - 1006744. DOT # 1812FR-1.

Abstract - A prototype airborne oil surveillance system was developed for the U.S. Coast Guard by Aerojet ElectroSystems Company. The multisensor system permits real-time day/night, all-weather detection, mapping and documentation of oil spills at sea. The system was installed aboard a Coast Guard HU-16 Albatross and flight tested off the California coast. Surveillance data were obtained from natural seeps, a series of controlled oil spills, routine shipping and targets of opportunity.

The airborne system consists of a sidelooking radar, a passive microwave imager, a multichannel line scanner, a position reference system, and a real-time processor/display console.

The system reliability and mapped oil spills and seeps for conditions ranging from dense undercast to clear, wind speeds from 0 to 26 knots and daytime to total darkness. Test results demonstrate that airborne oil surveillance is practical and the system can be invaluable to other Coast Guard missions.

Nil, Experimental and General Review, Highly Significant.

California Coast; December 1972-March 1973.

X-band sidelooking radar, 37 GHz passive microwave imaging system, Multispectral low light level TV, Multichannel line scanner, Position reference system, Real-time processor/display console.

Oil spills, Pollution, Remote Sensing, Sensors, Radar, Microwave, Infrared, Low Light Level TV, Surveillance.

Comments - This report details the fundamentals of the airborne oil surveillance system (AOSS) developed for the U.S. Coast Guard. All sensor systems carried onboard are described in terms of their operational characteristics, capabilities and limitations under varying conditions. Each sensor is described with reference to its potential ability to detect and map oil spills at sea and to identify the violator (i.e. ship). The AOSS system was tested on both controlled and accidental oil spills off the California coast. Conclusions of this study as well as recommendations for subsequent phases are well documented.

Engstrom, R.W. and R.L. Rodgers, 3rd, (February 1971), "Camera Tubes for Night Vision", Optical Spectra, pp. 26-32.

Introduction (Modified) - The greatest stimulus to the development of camera tubes for night vision has come from the military requirements for reconnaissance on night operations.

In the review we will be concerned with TV pickup with night-sky radiation. The sources of natural radiation are the stars, the airglow and zodiacal light.

The spectral distribution of the night-sky radiation differs considerably from that of sunlight. The optimum detector for night vision should take advantage of the red-infrared night-sky radiation.

Five, General Review, Normal.
Remote sensing, LLLTV.

Comments - This review includes a discussion on the operational characteristics and limitations of nighttime television viewing. Topics discussed include; the Photodetectors, Optical Considerations, Requirements for a LLLTV Camera, the Silicon Intensifier Target Tube, and the System's Theoretical Limitations.

Engstrom, R.W. and G.A. Robinson, (June 1971),"Choose the Tube - for L^3TV", Electro-Optical Systems Design, pp. 14-20. RCA. CCRS # 1001108.

Abstract - To see or not to see; that is the question. When it involves L^3TV the question is complex, and the camera tube is at the heart of it. Design light level is crucial. A laggy tube hinders seeing rapid target motion; blooming obliterates targets near bright lights. An image intensifier may help. Underlying all is tube cost.

Nil, General Review, Normal.
Remote sensing, LLLTV.

Author's Conclusions - Various TV camera devices have been examined for their applicability to low-light-level applications. Because there are a variety of applications and requirements, it is probable that all of the devices discussed have use in certain cases. In some applications, lag is not a problem; or, in others the lowest light-level operation is required. But for the most stringent requirements at the lowest levels of illumination, the most useful devices are the SIT camera tube and the Image Isocon tube, each of which has its own peculiar advantages.

E.P.S., (1974), "Remote Sensing of Oil Spills", Fisheries and Environment Canada", EPS-SEP-74-2.

Abstract - The Canadian federal government, working together with agencies of other governments, is conducting a number of programs related to detection and clean-up of oil spills in the environment.

In both the environmental assessment and clean-up aspects remote sensing technology provides a vital input. This report discusses the state-of-the-art in the remote detection of oil spills specifically in terms of Canadian experience and needs. Three basic types of sensor "packages" are discussed. These are: passive imagery techniques operating in the visible range of the spectrum, microwave systems and active or specialized techniques. Each of these three categories has certain advantages and disadvantages. For example, simple aerial photography or airborne multispectral scanner systems, operating in the visible range of the spectrum, are limited by meteorological conditions and to daytime operation.

Requirements of quasi-operational airborne systems include all weather capability which can be accommodated by microwave systems. Microwave systems can also be used for night-time surveillance and, under certain conditions, for estimating the thickness of oil. The third category covers instrumentation such as active laser line scanner systems (useful for night operations) and laser fluorosensors which may provide means of identification of the type of oil as well as distinguishing between oil and chemical effluents.

Twenty eight, General Review, Significant.

Multiband and Multispectral Techniques, Thermal Infrared Scanners, Microwave and Radar Systems, Laser Systems and Satellite Systems.

Remote sensing, Oil spills, Oil pollution, Photography,
Multispectral scanner, Thermal IR, Microwave, Radar,
Laser, Satellite.

Author's Conclusions (Modified) - In its simplest form the basic criteria for a remote sensing oil spill surveillance system are real time display, all weather capability and day or night operation. The ultimate system must be able to detect and identify the oil and/or species of oil.

In the present generation of sensors, some satisfy most of the basic criteria while others are more limited. Examples include, radar with its all weather capability but limited turn around time. Sensors in the visible range are limited by weather and daytime operation, however addition of active light sources (lasers) overcome some visible deficiencies.

Any surveillance system must, therefore, consist of all, or some, reasonable combination of the sensors in order to maximize its operational capability.

Estes, J.E. and L.W. Senger, (1974), "Imaging with Photographic and Nonphotographic Sensor Systems", Chapter 2, in Remote Sensing; Techniques for Environmental Analysis, University of California, Santa Barbara, CA. 36 pages. CCRS # 1005594.

Abstract - A fundamental prerequisite to interpreting information from remote sensing data is an understanding of the processes affecting the recording and display (imagery) of electromagnetic energy. It is difficult to condense and simplify the necessary explanations, but an attempt has been made in this chapter for the sake of beginning students. The organization of the chapter encompasses a discussion of (1) the factors involved in image formation, (2) sensor systems, and (3) collection, processing, and presentation of remote sensing data. A glossary of important remote sensing terminology appears as Appendix I.

Thirty two, General Review, Normal.
Variety of sensors.
Remote sensing, Sensor systems, Electromagnetic energy.

Author's Summary - This chapter presents the parameters involved and factors important for a basic understanding of imaging with photographic and nonphotographic sensor systems. Multiband/multispectral scanning may enhance the detection and identification of objects by utilizing contrast ratios that may exist in very narrow bands of the EM spectrum. Polarization, differential absorption and reflectance may also facilitate information extraction and ease of interpretation. This concept may or may not depend to some extent upon the use of sophisticated data reduction techniques. Based on optical density readings from a number of selected spectral channels,

tonal signatures of various conditions of a terrain feature and phenomena could be investigated and, hopefully with more data, automatically identified. Finally, it should be stressed that, although there are many sophisticated remote sensing techniques available, there is still a place for the individual with a small camera in a light aircraft. An image of an area, regardless of the quality, at least provides a record of a given scene and its associated phenomena at a given point in time.

Estes, J.E., L.W. Senger and P.R. Fortune, (1972), "Potential Applications of Remote Sensing Techniques for the Study of Marine Oil Pollution", Geoforum, pp. 69-81. University of California, Santa Barbara, CA. CCRS # 1004152.

Abstract - The detection and measurement of oil pollution in the marine environment are procedures requiring a broad range of instrumentation capabilities within an equally broad range of environmental conditions. Due to the complex behavior of oil on water, its susceptibility to transport and modification forces, and the physiochemical anomalies associated with its presence, both aerial and surface sensors are necessary to establish a complete and effective monitoring system. Remote sensors, operating in the ultraviolet, thermal infrared, and microwave portions of the electromagnetic spectrum, exhibit potentially good oil detection capabilities. Radar, in particular, possesses a strong capability for the mapping of an oil slick's areal extent since it is operative even under adverse weather conditions, day or night. Since no remote sensor system is presently capable of providing accurate information on the type or thickness of an oil slick, surface-based mechanisms must be utilized to gather ground truth data. These measurements, including the collection of radiometric, meteorological, and oceanographic information, are essential for a comparative analysis of remotely sensed data and their interpretation. More research is needed in the realm of remote sensing and ground truth data collection systems, including their coordination, if an operationally feasible system for monitoring marine oil pollution is to be developed.

Twenty three, General Review, Significant.

8.1 mm Dual-Polarized Radiometer; Dual-Polarized P, X, L and C Synthetic Aperture Radar.

Remote sensing, Oil pollution, Sensors.

Comments - Microwave radiation is more linearly dependent upon temperature than infrared radiation. Laboratory tests indicate the microwave radiometric signature of an oil film is universally proportional to sensor wavelength. The presence of an oil film modifies or reduces the ocean's surface roughness thereby changing its equivalent black body temperature and microwave signature.

Fantasia, J.F., T.M. Hard, and H.C. Ingrao, (June 1971), "An Investigation of Oil Fluorescence as a Technique for the Remote Sensing of Oil Spills", DOT/Transportation Systems Center, Cambridge, Mass., Report No. TSC-USCG-71-7, pp. 118. CCRS # 1000731.

Abstract - The feasibility of remote sensing of oil spills by laser-excited oil fluorescence is investigated. The required parameters are measured in the laboratory; these parameters are fed into a physical model to predict signal and background levels; and the predictions are verified by field experiments. Airborne detection, identification, and quantification of oil spills at sea are shown to be feasible with existing equipment, day or night.

Twenty six, Theoretical and Experimental, Highly Significant.

USCG Station in Point Allerton, Hull, Massachusetts;
July 1970 - June 1971.

Model 4-8203 Amenco-Bowmar Spectrophotofluorometer.

Oil spills, Oil, Remote sensing, Oil fluorescence, Laser.

Author's Summary - TSC has conducted a study and an experimental measurement program to determine the feasibility of using laser-excited oil fluorescence as a means of detecting, identifying, and quantifying oil spills.

The results of this program showed that: oil films 0.1 micrometers thick are detectable; each oil type has a distinct fluorescent spectral signature and, when correlated with API gravity fluorescent conversion coefficient and fluorescent lifetime, can be positively identified and classified; the areal extent of the oil spill can be accurately measured; and it appears oil film thickness, within certain limits can be measured with this technique.

The technique of remote sensing oil spills by laser excited fluorescence is technically feasible and well within the state-of-the-art. Furthermore, the components required to build a fluorescence sensor are available off-shelf.

Fenner, R.G., S.C. Reid* and C.H. Solie*, (1980), "A Multifrequency Evaluation of Active and Passive Microwave Sensors for Oil Spill Detection and Assessment", NASA, 17 pages. NASA, Lyndon B. Johnson Space Center, Houston, TX.; *Lockheed Engineering and Management Service Company Inc.*, Houston, TX. CCRS # 1030521.

Abstract - During 1979, two major accidental oil spills occurred in the Gulf of Mexico. On June 3, 1979, the PEMEX well, Ixtoc I, suffered a blowout and was not capped until the spring of 1980. On November 1, 1979, the freighter Mimosa collided with the tanker Burma-Agate at the entrance to the Port of Galveston. Five to six of the Burma-Agate's tanks were ruptured. Fire resulting from the collision prevented them from being sealed, and several thousand barrels of crude oil were subsequently spilled into the Gulf. These spills presented a major ecological threat to the Texas Gulf Coast, but offered a unique opportunity to evaluate multiple-frequency microwave sensor data for oil-spill detection and assessment.

During the summer of 1979, the NASA/Lyndon B. Johnson Space Center was evaluating an X-band synthetic aperture radar (X-SAR) system on a NASA WB-57 high-altitude aircraft. Imagery of the Ixtoc I spill was obtained on June 3, 1979, in a flight over the Gulf of Mexico, east of Harlingen, Texas. In November, the NASA Earth Survey #2 C-130 aircraft was being made ready for a data-gathering mission. As part of the premission sensor evaluation, several runs were made over the Burma-Agate spill gathering active/passive microwave and multispectral scanner data. In January 1980, an additional C-130 aircraft active/passive microwave data flight was made over the Ixtoc I well oil spill. Supportive photographic data was taken on these C-130 flights.

This paper will present an evaluation of the data gathered on these flights with respect to how active and

passive microwave sensors can best be used in oil-spill detection and assessment. Radar backscatter curves taken over oil spills will be presented and their effect on synthetic aperture radar (SAR) imagery will be discussed. Plots of microwave radiometric brightness variations over oil spills will be presented and discussed. Recommendations as to how to select the best combination of frequency, viewing angle, and sensor type for evaluation of various aspects of oil spills will also be discussed.

Twenty, General Review, Significant.

Burma-Agate spill, 1979 and Ixtoc I spill 1979; Gulf of Mexico.

13.3 GHz scatterometer, C-band radiometer.

Remote sensing, Oil spills, Microwave systems, Active/passive, Detection, Radiometer, Scatterometer.

Author's Conclusions - The data set used to prepare this paper was gathered under target of opportunity circumstances, thus all sensors were not available for all flights. However some general conclusions can be drawn. These are as follows:

(1) The presence of an oil spill on a water surface can be detected by a microwave radar system at incidence angles less than 45 degrees. Higher radar frequencies produce greater contrast between surfaces with and without oil on the surface. In the incidence angle range of 15 degrees to 25 degrees, there is greater surface return and maximum quieting due to the oil, thus reducing power output requirements on the radar.

(2) Windspeed over the surface affects the magnitude of the low difference between oil-covered and non oil-covered surfaces. The use of low ($< 20^\circ$) incidence angles at low microwave frequencies (L-band) provides less detectibility than higher microwave frequencies (Ku-band).

(3) An X- or Ku-band synthetic aperture radar (SAR) operating at orbital altitudes and incidence angles similar to Seasat would provide an effective means for detecting, monitoring, and tracking large oil spills.

(4) More study must be given to the effects of sea state on the active microwave oil-spill signature at incidence angles less than 45 degrees.

(5) Radiometers, while not having the resolution capability that SAR systems have, do have potential for determining oil thickness on the surface.

Fingas, M.F., W.S. Duval and G.B. Stevenson, (1979), "The Basics of Oil Spill Cleanup, (With Particular Reference to Southern Canada)", Environmental Protection Service, Environment Canada, Ottawa, Ontario. 155 pages. EPS, Ottawa, Ontario.

Foreword - During the last decade, many advances have been made in oil spill cleanup techniques and equipment. THE BASICS OF OIL SPILL CLEANUP is a general introduction to this technology, and summarizes data compiled by Environment Canada since 1972. The book explains what happens to oil when it is accidentally spilled on water or land and the specific cleanup strategies which are possible under varying environmental conditions. This material is designed to provide basic information to the public-at-large and to those persons who may actually have to deal with the cleanup of an oil spill, although it is not intended to serve as a field manual. Because oil spills in the Arctic environment create special cleanup problems which have been described in other Environment Canada publications, discussion here is focused upon cleanup methods and equipment which apply to spills in southern Canada. It should be emphasized that this report relates solely to oil spills, their behaviour on water and land, and the state-of-the-art of cleanup technology. The impact of oil spills on physical and biological resources will be the subject of a future publication.

In Canada, where oil is transported for great distances along coasts, on inland waters, and by land, the risks of a spill are considerable. It is hoped that the information contained in this document will be of interest to the public, as well as to industry and government personnel who may be responsible for environmental protection in the event of an oil spill.

Nil, General Review, Significant.

Comments - Discussed in this booklet are the following general topics: Oil Types and Characteristics, The Behaviour of Oil in the Environment, Response to Oil Spills, Containment, Recovery, Separation and Disposal Methods, Treatment of Spilled Oil, Shoreline Cleanup and Restoration and Land Spills. This booklet provides an excellent overview and background to Oil Spill Problems and Cleanup Methods.

Fleming, K. and J.P.P. Dick*, (1977), "Experience in Monitoring the Oil Content of Ballast Water Being Discharged by Tankers", Proceedings of the 1977 Oil Spill Conference (Prevention, Behavior, Control, Cleanup), New Orleans, Louisiana, pp. 165-168. Shell International Marine Limited, London, England; BP Tanker Company Limited, London, England*.

Abstract - The main practical features required of a shipboard monitoring system are outlined. A description is given of the Societe d'Etude et de Realisation d'Equipementes Speciaux (SERES) Directe Response Ultra-Rapide (DRUR) Type I oil content monitor and its installation onboard. Typical practical experience in monitoring tanker effluents is reviewed and some of the problems experienced, mainly with the sampling system, are highlighted. Practical experience then is discussed with regard to compliance with the 1973 International Convention for the Prevention of Pollution from Ships.

One, General Review, Normal.
SERES monitor.
Oil pollution, Monitoring, Oil content, Ballast water, Tankers.

Author's Conclusions - Monitoring of the oil content in tanker effluents is a relatively new experience and there is no gainsaying that it is no easy matter to surmount all of the problems to provide ships' personnel with workable and reliable system. In the common interest, this paper has chosen to highlight for consideration and eventual solution some of the practical problems already encountered, further experience may reveal that there are more.

Francois, R.E. and T. Wen, (August 1983), "Use of Acoustics in Localizing Under-Ice Oil Spills", Dept. of Transportation, U.S. Coast Guard, Washington, D.C., 17 pages. Applied Physics Laboratory, University of Washington, Seattle, WA. CG-D-26-83.

Abstract - Because of the development of oil resources in the Arctic, it has become necessary to devise methods of dealing with accidental spills of oil beneath and near sea ice. One of the first steps involved in cleaning up an under-ice oil spill is determining its exact location. If a means of rapidly locating an under-ice oil spill can be developed, appropriate recovery techniques that capitalize on that information can then be considered. This report describes a study undertaken to determine the feasibility of using underwater acoustics to specifically locate an under-ice oil spill whose general position is known. The first step was to measure the surface backscattering strength of sea ice at 100-300 kHz at low grazing angles. The results were then used to calculate the distance at which oil spills should be detectable. The design of an operational survey system should be relatively straightforward, once the parameters of the system are defined.

Twelve, Experimental and General Review, Normal.

Underwater Acoustics.

Acoustics, Oil spill detection, Surface backscattering, Strength, Under-ice sonar, Transducer.

Author's Summary - At low grazing angles, acoustic backscatter from the relatively rough ice-water interface should be substantially larger than that from the smooth oil-water interface. To obtain quantitative data on this difference, we conducted experimental investigations, in both the laboratory and the field, to determine the backscattering strength of flat sea ice in the frequency range of $f = 100\text{-}300$ kHz, and for grazing angles of $\theta = 10^\circ - 45^\circ$.

The surface backscattering strength, S_s, was found to be

$$S_s = -72 + 25 \log f + 15 \log \sin \theta, \quad \text{dB},$$

with a standard deviation of 5.25 dB.

The backscatter from an oil layer under ice was too small to be measured at small grazing angles with our system.

Using the empirical formula of Eq. (1), a sample calculation was made which showed that an under-ice sonar could effectively map the location of spilled oil under ice in an area several hundred meters in diameter. The required resolution, range, and display tradeoffs have yet to be calculated, but the necessary acoustic design information has been obtained.

Gildea, J., (April 1970), "Low Light Level TV Techniques", Applied Optics, Vol. 9, No. 10., pp. 2230-2235. Radio Corporation of America, Burlington, Mass. CCRS # 1013184.

Abstract - As the science of low light level sensing becomes better understood the demand for systems with this capability has increased considerably in recent years. Low light level television systems are part of these low light sensing devices in which interest has grown. Development of low light level TV systems has, in turn, stimulated technical advances in new tube types with improved performance, development of electronic techniques which enhance the over-all performance and design techniques which make the system more versatile and adaptable. A general look at some of these developments and techniques gives insight into the versatility and adaptability of low light level TV.

Nil, General Review, Normal.

Remote sensing, Low Light Level TV, Sensor.

Comments - Paper outlines and discusses the operating features, image tubes and spectral characteristics of Low Light Level TV.

Gross, A.D. and J. Kruus, (November 1971), "Remote Sensing of Oil on Water Using Laser Induced Fluorescence", Joint Conference on Sensing of Environmental Pollutants, Palo Alto, CA., pp. 1-5. Department of Environment, Ottawa, Ontario. AIAA Paper No. 71.1076; CCRS # 1002106.

Abstract - Sample spectra obtained in the laboratory of potential targets indicate that good excitation can be expected with a Helium:Cadmium laser operating at 441.6 nanometers. This wavelength represents a compromise between the variety of targets expected and available sources that would lend themselves to airborne use. Ground tests performed at 400 feet range with equipment scheduled for aircraft installation gave good response.

Four, Experimental, Highly Significant.
Laser Fluorosensor (441.6 nm).
Remote sensing, Oil, Laser, Fluoroscence.

Author's Conclusions - Laser induced fluorescence offers a reasonable method of remote sensing of oil on water or for tracing water flow with a dye tracer. There should be enough signal present for detection at low aircraft altitudes at nightime.

Other possible applications that will be investigated include identification of oil by its spectrum of fluorescence, geology, chlorophyll detection, and industrial effluent sensing.

Gross, H. and H.A. Hyatt, (1971), "Luminescence Induced by UV and Visible Lasers for the Remote Active Sensing of Materials from Ground, Air and Space", Reference Incomplete, pp. 869-875. McDonnell Douglas Astronautics Company, Huntington Beach, California. CCRS # 1000895.

Abstract - We have found that: (1) the same signature luminescence spectra can be produced with visible laser irradiation lines as with the classic UV, X-ray or charged particle irradiation in a wide variety of materials; and (2) the characteristic broad luminescent band of a material can be produced either totally by any laser line shorter than the band, or partially by any laser line within the band. The spectra, bandwidths, and quantum efficiencies for a preliminary set of six categories of materials (ground surface, plastic and coating, biological, geological, metallic, and fish and mineral oils) are presented and discussed.

In application to the active remote sensing of such materials (day or night) from distant ground, airplane or satellite platforms, analysis shows that, after appropriate optimizations are applied, measurable and useful signals can be obtained against the night-time sky background. The eye safety threshold is the prime limiting factor to increasing signal by increasing pulsed laser peak power, as is the luminescence decay time for decreasing noise background by decreasing the sampling time.

At present, this active technique for the remote sensing of materials by laser-induced luminescence signatures will require extensive laboratory and field investigations to establish its identification utility. Through a unique set of spectral emission, time domain, polarization and other data produced with high spatial resolution by this method, valuable compositional information for the application of correlation spectroscopy and pattern recognition techniques could be obtained. Alone or in combination

with other techniques, it offers potential for the remote detection, discrimination, identification and monitoring of a wide variety of materials.

Eight, General Review, Significant.

UV and Visible Lasers.

Remote sensing, Luminescence, Active, Lasers, Visible, Ultraviolet, Ground based, Airborne, Satellite.

Author's Conclusions - As has been illustrated, all of the remote sensing advantages of a laser as an active irradiation source, can be usefully applied in the production of characteristic luminescence from various target materials. The hitherto unrecognized fact that laser wavelengths in the visible can produce such luminescence provides additional important advantages for application from ground, airplane and satellite platforms. Even though the nighttime sky background is a serious problem to be reckoned with in every application, appropriate application of a variety of optimization options can circumvent certain limitations and provide measurable, useful signals at large ground distances or at airplane and satellite altitudes. Presently in its pioneering phase, the application of this technique to remote sensing for a variety of purposes remains to be clearly established. Its potential is realistically promising.

Gross, H. and M. Muramoto, (April 1974), "Crude and Refined Petroleum Oil Structured Luminescence Signatures Induced by UV Laser or Lamp and Their Remote Sensing Applications", Proceedings of the Ninth International Symposium on Remote Sensing of Environment, Vol. III, pp. 1747-1759. McDonnell Douglas Astronautics Company, Huntington Beach, California. CCRS # 1005080.

Abstract - For design purposes question has arisen recently whether luminescence emission spectra of petroleum oils, induced by a single wavelength, are single or multiple peaked. Both have been observed by those using UV lasers or lamps. Structured luminescence spectra of oils are produced by us with different UV lines from a CW argon ion laser (2573Å) and a mercury glow lamp (2573Å). Ten virgin crude oils (one asphalt base, five heavy crude, four light crude) and one refined fuel oil were studied without dilution or containment. "As measured" spectra (S-20 photocathode on quartz window) tend to have one principal peak, with secondary features in the longer and shorter wavelength direction. "Spectrally corrected" spectra, however, show resolved structure of two or more peaks, shifting the more intense peak wavelengths in the red direction. "As measured" peaks range from the near UV to the orange, whereas "spectrally corrected" peaks range from the near UV to the near IR. It appears feasible to map an oil spill with a simple active system, using as few as four broadband photometer channels for classifying oil into four categories. Exact identification of each oil type, however, would require a more sophisticated system.

Six, Experimental and General Review, Significant.

CW argon ion laser (2573Å) and a Mercury glow lamp (2573A).

Remote sensing, Luminescence signatures, Lasers, Applications, Crude and refined petroleum.

Author's Conclusions - The laboratory investigation of crude and refined oil luminescence signatures evidenced by different UV lamp and laser sources shows: (1) the undiluted oil samples, representative of field samples, have structured signatures; (2) the signatures from a utilitarian standpoint are of two kinds: "as measured" which are sample and instrument dependent, and "spectrally corrected" which are solely sample dependent; (3) the majority of applications are best served by the simpler, more cost-effective instrumentation exploiting "as measured" signatures for either the broad classification of oils or simply for oil-water discrimination; (4) the unique identification of each oil type, however, requires the more sophisticated, more costly instrumentation exploiting the peaks and shape of "spectrally corrected" signatures, which provide the absolute basis for intercomparison of field and data bank signatures; (5) other hazardous materials, sometimes acting as interfering backgrounds to oils, are capable of remote identification and estimation of concentration by the combination of active absorption and luminescence measurements.

The potential for uniquely identifying petroleum oils by laser induced luminescence signatures is demonstrated as being achievable. Better data acquisition for monitoring and assessing our hydrospheric environment and its pollution is possible by this approach.

Grover, C.G. and W.L. King, (August 1977), "Night Identification Camera", Proceedings from the Society of Photo-Optical Instrumentation Engineers, Vol. 108, Optics in Security and Law Enforcement, pp. 39-44. Naval Surface Weapons Center, Silver Spring, Maryland. CCRS # 1029000.

Abstract - Many fields of photographic applications have a specific need for a compact, intensified camera for taking pictures of moving objects under low light level conditions. In obtaining the required camera characteristics there are several trade-offs to be considered. This design is based on maximum camera gain and minimum camera size and weight with electrical gating. The system is capable of hand-held operation at 1/3 full moon. A prototype which has been constructed and is currently undergoing field evaluation is described.

Five, Experimental and General Review, Significant.

Nighttime Identification Camera, 25 mm, electronically gated MCP image intensifier tube on a modified 35 mm camera body.

Remote sensing, Nighttime, Low light level conditions, Photographic system.

Comments - The design trade-offs which determined the performance of the intensified low light level photographic camera are discussed herein. The design philosophy for the construction of a camera for specific applications requiring high sensitivity, small size, and good information recording ability have been considered by these authors.

Guinard, N.W., (May 1971), "The Remote Sensing of Oil Slicks", Proceedings of the Seventh International Symposium on Remote Sensing of Environment, Ann Arbor, Michigan, II, pp. 1005-1026. Naval Research Laboratory, Washington, D.C.
CCRS # 100904.

Abstract - Radar is presently being used by the Naval Research Laboratory to detect the area of coverage of oil spills. The effort is being sponsored by the U.S. Coast Guard. In the first phase of the study, two types of measurement programs were conducted. The first was the mapping of the accidental spill produced when the Tanker ARROW collided with Cerberus Rock in Chedabucto Bay, Nova Scotia, while the second was conducted over a programmed spill off the California coast. In both cases, imagery was acquired as a function of radar frequency, polarization and viewing angle by the NRL Four-Frequency Radar System. As a result, both the feasibility and utility of the radar approach has been established and various characteristics of the oil signature have been determined. Experiments are continuing over both programmed and accidental spills to accumulate a data base from which the relationships between image contrast and radar variables, sea state and oil type and thickness can be obtained as well as to acquire operational data which can provide guidance into the deployment and utilization of the technique.

Seven, Experimental, Significant.

Nova Scotia, California; February 1970; October-December 1970.

NRL 4 - Frequency radar.

Remote sensing, Oil spill, Thickness, Polarization, Radar wavelength, Incidence Angle.

Author's Conclusions (Modified) - Radar mapping of oil slicks offers a feasible and highly flexible solution to the problem of policing and monitoring the coastal areas of the

United States for oil pollution. Radar possesses the all-weather, day/night capability and large swath width potential required by this application. Three types of configurations are suitable for this effort; real aperture forward scanning radar, real aperture side looking radar and synthetic aperture radar.

As a result of the two deployments of the Four-Frequency Radar a large quantity of oil slick imagery has been obtained. Although large gaps still exist in the data base, tentative conclusions may be drawn;

1) Image contrast is a strong function of the polarization of the radar signal. Vertically polarized signals produce maximum contrast.

2) There is a strong functional relationship between the incident radar wavelength, the sea state and the thickness of the oil film.

3) The minimum thickness of oil detected in this study was 1.0 micron in low sea states. Since the contrast of the slick image was large under these conditions, 0.5 microns should be detectable.

4) A spatial resolution of 100 to 300 feet in both range and azimuth directions are adequate for slick definition.

5) There is some evidence that radar may be used to determine oil thickness, however, there has been no evidence that oil type yields a distinctive signature.

6) The radar viewing angle should be within 45 degrees of the horizontal to avoid specular returns.

Harrald, J.R., K.R. Karwan* and C.M. Stone**, (1977), "Prevention of Pollution During Oil Transfer Operations: An Evaluation of USCG Preventive Actions", Proceedings of the 1977 Oil Spill Conference (Prevention, Behaviour, Control, Cleanup), New Orleans, Louisiana, pp. 223-227. Marine Environmental Protection Division, U.S.C.G., Washington, D.C.; School of Urban and Public Affairs, Carnegie-Mellon University, Pittsburgh, PA*; Department of Economics and Management, U.S.C.G. Academy, Groton, Connecticut**.

Abstract - During its journeys from a production facility to a refinery, the most probable time for oil to enter the water is during vessel cargo-transfer operations. This paper describes the origins, implementation, and effects of the U.S. Coast Guard's operational and regulatory program designed to prevent oil transfer-related discharges. Statistical data from the USCG Pollution Incident Reporting System (PIRS) is used to measure the effectiveness of these actions. A review is presented of the results of an on-scene transfer monitoring program conducted in 1972 in Seattle, Washington.

Coast Guard pollution prevention regulations (33 CFR 154-156) were designated to prevent the occurrence of discharges during transfer operations. An analysis of the effectiveness of these regulations and the present nationwide transfer operations monitoring program is presented. The paper concludes that the Coast Guard preventive program has had a measurable effect on the incidence of transfer-related pollution incidents.

Seven, General Review, Normal.
Puget Sound, 1971-1972.
Oil pollution, Prevention, U.S.C.G., Monitoring.

Comments - This paper illustrates a case in which a pollution problem was identified, preventive strategies were developed, tested and implemented, and the effectiveness of these actions were evaluated.

Hawkins, R.K., A.L. Gray, V. Thomson[*] and R.A.Neville[*], (April 1979), "Observation of Two Test Oil Spills with a Microwave Scatterometer and a Synthetic Aperture Radar (SAR)", presented at the Workshop of the NATO-CCMS Pilot Study on the Use of Remote Sensing for the Control of Marine Pollution, 21 pages. Canada Centre for Remote Sensing; Intera Environmental Consultants Ltd.[*]. CCRS # 1028050.

Abstract - A microwave scatterometer and a synthetic aperture radar (SAR) were flown over two test oil spills off the coast of New Jersey in November, 1978. This paper examines the microwave data obtained from this mission and draws some tentative conclusions.

The CCRS, Ryan 13.3 GHz microwave scatterometer was used to quantify the depression in the microwave backscattering coefficient, $\Delta\sigma_0$ resulting from the oil slick on the ocean surface. This scatterometer can transmit vertically or horizontally polarized microwaves and can receive simultaneously both like-and cross-polarized returns. Scattering cross sections were measured over a range of incidence angles from 60° aft of the aircraft to 60° fore. Over this range of angles, VV and HH polarizations showed approximately the same depression in radar cross section with the presence of the oil. The depression is negligible at incidence angles below 10° and increases to approximately 12 dB for incidence angles between 30° and 55°. For angles of incidence greater than 30°, the average backscattering cross section, σ_0 , due to sea clutter is greater in the VV mode than in the HH mode. This confirms that a radar with a vertically polarized transmitter and a vertically polarized receiver may be preferable for the detection of oil slicks on the water surface because the sea clutter-to-noise ratios will be higher. These results, however, suggest that for angles of incidence likely to be found in satellite radars, (and some airborne radars), a 13.3 GHz system using either

like-polarized mode (VV or HH) will permit satisfactory detection of oil slicks.

The ERIM (Environmental Research Institute of Michigan) SAR was flown over the same slick and imaged in both L and X band. Horizontally polarized microwaves were transmitted and both polarizations received while the slicks were imaged over the narrow range of incidence angles from 33° to 49°. Initial optical processing of this imagery shows the cross-polarized imagery to be of very low contrast. The like-polarized X band imagery is superior in both resolution and contrast to the like-polarized L band imagery. Small signal suppression in the vicinity of extremely bright targets such as ships (or icebergs) has been observed and this artifact may appear to be similar to oil. For the sea states present (sea state 1-2) little variation in the oil-water contrast was noted when the slick was imaged from different directions.

Seven, General Review, Significant.

New Jersey Coast; 1978.

CCRS-Ryan 13.3 GHz microwave scatterometer, ERIM synthetic aperture radar.

Remote sensing, Oil spills, Detection, Scatterometer, SAR.

Author's Conclusions (Modified) - Tentative conclusions of the utility of the scatterometer; 1) The suppression of the ocean backscatter cross section is negligible at an incidence angle of 10° and increases to approximately 7 to 12 dB for incidence angles between 30° and 55°. 2) The combination of horizontally polarized transmit and receive radiation (HH) leads to a comparable suppression of the radar cross section when compared to VV data for incidence angles, less than 60°. 3) Neither cross-polarized component of the backscatter radiation showed larger backscatter suppression than the like-polarized components.

Hickman, G.D., J.E. Hogg, E.J. Friedman, and A.H. Ghovanlou, (October 1972), "Application of a Pulsed Laser for Measurements of Bathymetry and Algal Fluorescence", Proceedings of the Eighth International Symposium on Remote Sensing of Environment, Vol. 1, ERIM. Sparcom, Inc., Alexandria, Virginia. CCRS # 1003673.

Abstract - A number of applications using a pulsed N_2/Ne tunable dye laser as a remote sensor are currently being investigated at Sparcom. Two programs which have been extensively studied are 1) laser bathymetry and 2) laser stimulated fluorescence of algae. Laser transmission measurements were performed in turbid water made from resuspended bottom sediment and water taken *in situ* from eastern U.S. coastal and bay sites. The results indicate it should be possible to measure bathymetry in the coastal zone to depths corresponding to 15 attenuation lengths from an altitude of 500 meters. The upper limit on the capability of the bathymetry system has been determined for a spot size (at the bottom) of $\leq 40\%$ of the actual depth and for a detector field of view of 5 milliradians. Laser excitation spectra for various types of algae ranged from 4200 to 6750 Å, while their fluorescent spectra ranged from 5800 to 6850 Å. Since the results of these experiments show a wide variation in both the excitation and fluorescent wavelengths, the possibility exists that this technique could be used for detecting and identifying various algal classes. Extrapolation of measurements which were made of laser stimulated fluorescence as a function of both the algal cell concentration and distance between the algae and the laser/receiver indicate that a laser system operating from an altitude of 500 meters should be capable of detecting chlorophyll concentrations as low as 1.0mg/m^3.

Two, Experimental, Normal.

Delaware Bay; August 1971.

Pulsed Laser.

Remote sensing, Pulsed laser, Fluorescence, Bathymetry, Algae, Measurements.

Author's Conclusions (Modified) - The results of laser bathymetry program showed that to a good approximation, the turbidity of natural bay waters can be stimulated to a high degree in the laboratory for making laser transmission/ scattering measurements. For the results obtained for Delaware Bay it has been shown that the maximum water depth measuring capability for an airborne laser system, at an altitude of 500 meters, is 15 attenuation lengths.

The result of the laser stimulated fluorescence experiments on algae showed that the various species had different fluorescence spectra depending on their pigments.

Hickman, G.D., J.E. Hogg*, A.R. Spadaro*, and M. Felscher*, (1969), "The Airborne Pulsed Neon Blue-Green Laser: A New Oceanographic Remote Sensing Device", Reference Unknown, pp. 1061-1066. Exotech Incorporated, Rockville, Maryland; Syracuse University Research Corporation, Syracuse, New York*. CCRS # 1000777.

Abstract - The Neon Laser (5401 Å) has been used as a remote airborne bathymetric sensor to water depths as great as 26 feet. Optical transmission/angular scattering experiments were made in waters of varying turbidity using a 20,000 liter water tank. The turbidity changes were accomplished by using 1) finely crushed quartz and 2) natural sediment from San Francisco Bay. Nearly identical results were obtained from both types of sediment. Future deployment of the airborne laser in oceanographic studies include: (1) delineation of nearshore and coastal morphology, (2) identification and distribution of plankton, (3) synoptic tracking of surface/subsurface water currents, (4) measurement and determination of water turbidity, and (5) identification of substrate composition.

Nil, Experimental and General Review, Normal.
Lake Ontario.
Pulsed Neon Blue-Green Laser.
Remote sensing, Fluorescence, Oceanography, Laser.

Author's Results - The results of these measurements have shown that transmission/scattering experiments can be performed in a controlled environmental water tank facility. Such measurements can be of real value in attempting to unravel some of the complex light attenuation problems. Unfortunately one is limited to the number of attenuation lengths that can be measured in a relatively small tank. However, since one is power limited in the airborne bathymetric system to a fairly small number of attenuation lengths, (~4-6), one can nonetheless obtain a large amount of useful data for the nearshore surveillance problems in such a facility.

Hoff, R.M. and F.A. Froude, (July 1978), "Lidar Observation of Plume Dispersion in Northern Alberta", Atmospheric Environment, Vol. 13, pp. 35-43, Atmospheric Environment Service, Downsview, Ontario.

Abstract - The particulate plume from the power plant of Great Canadian Oil Sands, Ltd. was observed using a mobile laser radar (LIDAR). Thirteen Eulerian average cross sections were obtained from which the horizontal and vertical dispersion coefficients, plume rise and plume bearing were derived. The methodology for extracting these parameters from LIDAR scans is presented. Comparison with Gaussian plume formulae show valley effects and wind shear under stable regimes to be important for this region.

Fourteen, General Review, Normal.
Tar Island Region of Alberta.
Mobile Laser Radar.
Remote sensing, Oil pollution, Laser radar.

Author's Conclusions - The use of a LIDAR when coupled to a method to directly extract dispersion statistics from the data has been shown to yield useful analytical capabilities for pollution dispersion estimates. As a case in point it has been shown that under stable conditions in Northern Alberta, simple Gaussian plume formulations lead to erroneous predictions of plume dispersion and attention is drawn to several effects, including plume dynamics in the buoyant regions, topography and wind shear.

The techniques used to obtain the moments of the plume concentration distribution do not rely on any a priori assumptions about plume shape. The higher moments of the distribution show promise of yielding valuable information about wind shear effects in plume dispersion.

Hoge, F.E. and R.N. Swift*, (October 1980), "Oil film thickness measurement using airborne laser-induced water Raman backscatter", Applied Optics, Vol. 19, No. 19, pp. 3269-3281. NASA Wallops Flight Center, Virginia; EG&G Washington Analytical Services Center, Inc.*, Pocomoke City, Maryland. CCRS # 1025716.

Abstract - The use of laser-induced water Raman backscatter for remote thin oil film detection and thickness measurement is reported here for the first time. A 337.1 nm nitrogen laser was used to excite the 3400 cm^{-1} OH stretch band of natural ocean water beneath the oil slick from an altitude of 150 m. The signal strength of the 381-nm water Raman backscatter was always observed to depress when the oil was encountered and then return to its original underdepressed value after complete aircraft traversal of the floating slick. After removal of background and oil fluorescence contributions, the ratio of depressed-to-undepressed airborne water Raman signal intensities, together with laboratory measured oil extinction coefficients, is used to calculate the oil film thickness.

Twenty, Experimental and General Review, Significanc.

337.1 nm Lidar.

Remote sensing, Oil thickness, Fluorescence, Laser Raman backscatter.

Comments - The airborne lidar detection and measurement of thin oil films on seawater have been successfully demonstrated using the Raman suppression technique together with a single contiguous oil layer computational model. The theory, instrument description, experiments and final results are outlined in this paper.

Hollinger, J.P., J.E. Kenney and B.E. Troy, (November 1972), "A Versatile Passive Microwave Imaging System", Naval Research Laboratory, Washington, D.C., 26 pages. Space Sciences Division. NRL Memorandum Report 3164.

Abstract - A new passive microwave imaging system has been assembled at the Naval Research Laboratory and flight tested using the NASA/Wallops C-54 aircraft. The system incorporates an oscillating mirror and interchangeable radiometer units making it particularly adaptable to variations in its operational frequency, polarization, and angular resolution. Flight tests of the system have been conducted at 90 GHz and simultaneously at 22 and 31 GHz using a dual frequency radiometer. The imaging system and data processing are described and some of the initial flight test results at 90 GHz are presented.

Six, Experimental, Significant.

Passive Microwave Imager (90, 22 and 31 GHz).

Remote sensing, Microwave imaging, Microwave radiometry, Image processing.

Comments - The system used in this experiment is described and the data processing and test results are documented.

Hoult, D.P., S. Wolfe, S. O'Dea and J.P. Patureau, (March 1975),
"Oil in the Arctic", Dept. of Transportation, U.S. Coast
Guard, Washington D.C., 218 pages. Massachusetts Institute
of Technology, Cambridge, Mass. Report No. CG-D-96-75.

Abstract - This report describes the results of several researches on the behavior of oil spilled in the arctic. Included are studies on evaporation, spreading and maximum extent of oil spilled on ice, and the behavior of oil spilled under ice. Physically sound theories are developed which correlate well with laboratory and field data.

Thirteen, General Review, Significant.

Oil pollution, Arctic oil pollution, Oil on ice, Oil under ice.

Author's Summary - It is helpful to conclude this report by commenting on the practical application of the results of this work. The most important result, which is substantiated by all the research to date, is that the oil in even a very large Arctic spill will be confined to a very small area due to natural processes. This simple, general, conclusion is supported by both the spreading and pocketing experiments as well as the studies on oil evolution.

As a corollary to this result, it seems clear that, unlike the situation in temperate waters, there is little incentive to promptly clean up large oil spills, as the area of the oil spill will not measurably increase with time, while the oil remains in contact with sea ice.

Houston, W.R., D.G. Stephenson* and R.M. Measures, (September 1973), "Lifes: Laser Induced Fluorescence and Environmental Sensing", Proceedings of the Use of Lasers for Hydrographic Studies, pp. 153-169. University of Toronto, Toronto, Ontario; Institute for Aerospace Studies.*

Abstract - A laboratory investigation has been conducted to evaluate the detection and identification capabilities of "laser induced fluorescence" as a remote sensing technique for the marine environment. The relative merits of fluorescence parameters including emission and excitation profiles, intensity and lifetime measurements are discussed in relation to the identification of specific targets of the marine environment including crude oils, refined petroleum products, fish oils and algae. Temporal profiles displaying the variation of lifetime with emission wavelength have proven to add a new dimension of specificity and simplicity to the technique.

Eleven, General Review, Significant.

Laser Fluorosensor.

Remote sensing, Laser fluorosensor, Fluorescence, Environmental applications, Oil pollution.

Author's Conclusions (Modified) - If a laser induces fluorescence in a remote target of the marine environment, the process of identification of the target must progress through two phases. The first phase is the target family identification. In most cases we have studied, a measurement of the peak emission wavelength and emission profile bandwidth is sufficient; however, the differentiation of crude oils and fish oils may require knowledge of the complete temporal wavelength profile.

The second phase is species identification within the family. Crude oil types may be classified by a matrix of fluorescence parameters including peak emission wavelength, relative intensity, peak excitation wavelength and lifetime at the peak emission wavelength. The ground truth parameter of API gravity may be added to the matrix.

The problem has been found to be complicated by aging effects; however, if crude oil species identification is accomplished, then the aging effects may be used to determine spill occurrence time.

Intera Environmental Consultants Ltd., (May 1982), "Analysis of Remote Sensing Data Collected for Detection and Mapping of Oil Spills", NASA, Langley Research Center, Hampton, Virginia, 240 pages. CCRS # 1037084.

Abstract - Airborne, remotely sensed data of the NASA Wallops controlled oil spill, collected by the Canada Centre for Remote Sensing in November 1978, were corrected, reduced and analysed. Sensor performance comparisons were made by registering data sets from different sensors, which were near-coincident in time and location.

Multispectral scanner images were, in turn, overlayed with profiles of correlation between airborne and laboratory-acquired fluorosensor spectra of oil; oil-thickness contours derived (by NASA) from a scanning fluorosensor and also from a two-channel scanning microwave radiometer; and synthetic aperture radar X-HH images. Microwave scatterometer data were correlated with dual-channel (UV and TIR) line scanner images of the oil slick.

Twenty, General Review, Significant.

Two aircraft, Various sensors, November 2nd and 3rd, 1981.

Oil slicks, Remote sensors, Laser fluorosensor, Multispectral band scanners, SAR, Microwave radiometer, Microwave scatterometer.

Author's Conclusions (Modified) - Each of the sensors used in this study has some capabilities and characteristic limitations for oil slick detection and measurement. When used in an orchestrated manner, however, multi-sensor coverage can exhibit a synergism, due to the independent variation of oil targets by complementary sensors. Additionally, the capabilities of one sensor can offset the limitations of another.

To date, the intercomparison of data from differing sensors is a difficult task, which is hampered further when the sensors are carried on different aircraft. Future tests of multi-sensor oil spill mapping must give substantial consideration for geometric and time referencing among sensors. Much additional experimentation and development is required before multi-sensor data can be routinely overlaid and analysed in combination, in real time, which would be an ideal monitoring scheme.

Intera Environmental Consultants Ltd., (March 1983), "State-of-the-Art Survey of Oil-Spill Detection, Tracking and Remote Sensing in Cold Climates", Environmental Protection Service, Environment Canada, Ottawa, Ontario. 65 pages. CCRS # 1038553.

Abstract - The detection and subsequent tracking of the fate of marine oil spills in cold climates is afforded by recent technological developments, as well as judicious use of the human visual system. A variety of buoys is now available for following the progress of oil on water, or in an ice-infested environment. Active, radio frequency transmitters and navigational systems will keep accurate track of the progress of these buoys. Airborne and, to a certain extent, satellite-borne sensors can be used to probe for oil on or under the water, or entrained in, or trapped under ice. From the more conventional camera systems, to the more sophisticated laser, radar and acoustic sensors, each has its own advantages in determining the existence, measuring the spatial distribution, or defining the type of oil that has been released into the environment.

Seventy one, General Review, Highly Significant.

Surface, Airborne and Satellite Systems.

Remote sensing, State-of-the-art, Surface System, Airborne sensors, Satellite sensors, Detection, Monitoring, Oil spills, Oil pollution, Ice.

Author's Summary (Modified) - A variety of instruments have been used to address the problem of oil detection. These state-of-the-art techniques have been reported by the authors of this paper and their capabilities and limitations discussed. The techniques included here were; SLAR, Buoys, Laser Fluorosensor, LLLTV, Passive Microwave Radiometry, Multispectral Scanners and Satellite Systems.

Inter-Governmental Maritime Consultative Organization, (October 1976), "Manual on Oil Pollution: Section I (Prevention)", London, England, pp. 7-27.

Introduction (Modified) - Because of the vast increase in oil production over the past fifty years and the consequent increase in the amount of oil carried by sea, pollution of the sea by oil has increased and the risk of further pollution is greater now than at any time in the past. Not only does this type of pollution pose a serious threat to coastal amenities, it can also cause the death of large numbers of sea birds and damage marine plant and animal life. This could eventually lead to a fall in the productivity of the sea which is one of mankind's most important sources of food.

This manual deals with the procedures for the handling of oil cargoes, bunkering, discharges of oil residues, tank washings, ballast and bilge waters, by methods designed to prevent oil pollution of the sea.

Nil, General Review, Normal.
Oil pollution, Operating requirements, Ships, Tankers.

Comments - This section of the manual dealt only with the avoidance, or prevention, of oil pollution of the sea. The precautions necessary to reduce oil pollution are discussed in detail.

Inter-Governmental Maritime Consultative Organization,
(February 1980), "Manual of Oil Pollution, Section IV",
London, England, pp. 9-19.

Introduction - There is a continuing and growing concern over the environmental risks of increased marine transport of oil. Approximately eighty per cent of the world's oil spills from vessels are the result of routine vessel operational discharges conducted at sea. The elimination of these discharges is a goal of the Inter-Governmental Maritime Consultative Organization (IMCO) through such vehicles as the International Convention for the Prevention of Pollution of the Sea by Oil, 1954, as amended, the International Convention for the Prevention of Pollution from Ships, 1973 and the Protocol of 1978 thereby adopted by the International Conference on Tanker Safety and Pollution Prevention, 1978. Operational discharges, if conducted in accordance with good operating procedures and International Convention are, for the most part, not recoverable and it is necessary to deal with them only occasionally. On the other hand, careless operating procedures and maritime accidents can result in massive slugs of oil which must be dealt with in one form or another to reduce harmful effects.

The actual threat to the environment from oil spills has been under debate since about 1967 when one of the most renowned oil spills occurred off the British coast. Location, temperature, and product are but three of the many variables which influence the level of impact on the environment from an oil spill. Direct wildlife mortalities, damage to marine ecosystems, loss of recreational resources and damage to economies all can occur as the result of an oil spill but losses can often be minimized if correct countermeasures are taken.

Nil, General Review, Significant.
Oil pollution, Characteristics, Processes.

Comments - This section of the Manual on Oil Pollution provides an overview of the practical ways to deal with oil spills. It is by no means all-inclusive, but does suggest many ways to combat a spill.

Isaacson, A.D., M. Rosenblatt and Son, Ltd., (1979),
"Shipboard Oily Water Pollution - A Practical Guide for
the Owner and Designer", Proceedings of the Eleventh Annual
Offshore Technology Conference, Vol. 4, pp. 2183-2192.

Abstract - This paper is presented as an aid in understanding the U.S. and International (IMCO) regulations with regard to shipboard oil pollution and as a guide for selecting and installing an oily water separating device as it pertains to a particular situation. The information presented is based upon recent projects in which various type vessels have been upgraded to comply with oil pollution regulations. The latest information regarding IMCO and US Coast Guard regulations as applicable to new and existing vessels are presented as well as means for complying. Covered are the various areas of possible shipboard oily water contamination such as machinery bilges, tank cleaning and oil transfer operations. Commercially available oily water separators are discussed and presented to assist the reader to judge the applicability for his particular case.

Twelve, General Review, Normal.
Shipboard, Oil pollution, Water pollution, Regulations.

Comments - Topics discussed in reference to this paper include; shipping regulations (proposed and existing), oily water separators, bilge systems, ballast and tank cleaning systems, oil content monitors and alarms, etc.

The International Tanker Owners Pollution Federation Ltd., (1981), "Aerial Observation of Oil at Sea", Technical Information Paper, No. 1, pp. 4-6, London, England.

Introduction - Aerial reconnaissance is essential for an effective response to oil spills, both to facilitate the location of oil at sea and to improve the control of clean-up operations. It is necessary to locate the oil in order that timely measures may be taken to protect coastlines threatened by pollution. However, finding the oil and then interpreting its appearance in terms of amount and type is often difficult. Weather and sea state in the search area can be unfavourable and the resemblance between floating oil and other phenomena is frequently deceptive. The aim of this leaflet is to illustrate some of the common pitfalls in aerial observation of oil floating at sea and to identify reliable reporting practices.

Nil, General Review, Normal.

Comments - This paper reviews the general requirements for aerial reconnaissance and the visual appearance of oil at sea.

Jones, D., R. Landers* and A. Pressman*, (1977), "Aerial Photographic Applications In Support of Oil Spill Cleanup, Control and Prevention", Proceedings, 1977 Oil Spill Conference (Prevention, Behaviour, Control, Cleanup), New Orleans, Louisiana, pp. 221-222. EPS, Washington, D.C.; *EPA, Las Vegas, Nevada.*

Abstract - For several years the Environmental Protection Agency and EPA contractor aircraft have carried out aerial photographic missions, mapping the areal extent and shoreline contamination from major oil spills in support of cleanup and control operations and environmental damage assessment. In 1975, EPA began a program of aerial photographic overflights of selected onshore oil production, storage and processing facilities to support the compliance monitoring of EPA's oil pollution prevention regulation. This paper describes the aerial mapping program and also discusses specific applications of aerial photography to oil pollution prevention compliance monitoring.

Nil, General Review, Normal.

Photographic camera.

Remote sensing, Oil spills, Cleanup, Prevention, Control, Visible region, Aerial photography.

Author's Summary - High resolution color aerial photography in support of oil spill cleanup, control and prevention now is a proven operational application, and but one of many remote-sensing operational applications in identifying pollution problems and providing a data base for enforcement purposes. As air, land and water pollution are encountered almost everywhere, the aerial platform with state-of-the-art remote sensors is a natural for assessment and has proven to be very cost effective. The latter is true not only with regard to value of data obtained versus cost of data acquisition and handling, but particularly with respect to the magnitude and variety of the data obtained for which ground acquisition alone would be prohibitively expensive.

Kennedy, J.M., and E.G. Wermund*, (Dec. 1971), "Oil Spills IR and Microwave", Journal of the American Society of Photogrammetry, Vol. XXXVII, No. 12, pp. 1235-1242.
TRW Systems; Remote Sensing Inc., Houston, Texas.*
CCRS # 1004272.

Abstract - Examples indicate that the utilization of thermal infrared and microwave radiometric data, approached from a systems point of view, are of value to operational groups charged with cleaning up oil pollution in ocean and coastal water environments. In addition, these systems may be used to upgrade and increase the value of theoretical models so that they more clearly agree with field observations. The preliminary findings of this study point to fruitful areas of directed applications re-research and the techniques should be pursued with vigor and proper governmental funding. This would ultimately result in greatly reduced costs for spill tracking, source identification, determining the terminal destination and determining the efficiency of clean-up operations.

Six, Theoretical and Experimental, Highly Significant.
110 miles SE of New Orleans; March 1970;
13.6 GHz (22 mm) Microwave Radiometer.
Oil spill, thickness, volume, flow rates, radiometric temperature, IR temperature.

Author's Conclusions - The utilization of thermal infrared and microwave radiometric sensors, approached from a systems point of view, are of value to operational groups charged with cleaning up oil pollution in ocean and coastal water environments. In addition, these systems may be used to upgrade and increase the value of theoretical models so that they more nearly match field observations. The preliminary finding of this study points to fruitful areas of directed applications research and the techniques should be pursued with vigor and proper government funding. This would ultimately result in greatly reduced costs for spill tracking, source identification, determining the terminal destination and determining the efficiency of clean-up operations.

Kim, H.H., P.O. Cervenka* and C.B. Lankford*, (October 1975), "Development of an Airborne Laser Bathymeter", NASA, Washington, D.C., 39 pages. NASA Wallops Flight Centre, VA; Computer Sciences Corporation, Wallops Island, VA.*

Abstract - An airborne laser depth sounding system has been built and taken through a complete series of field tests. Two green laser sources have been tried: a pulsed neon laser at 540 nm and a frequency-doubled Nd:YAG transmitter at 532 nm. To obtain a depth resolution of better than 20 cm, the pulses had a duration of 5 to 7 nanoseconds and could be fired up to at rates of 50 pulses per second. In the receiver, the signal was detected by a photomultiplier tube connected to a 28 cm diameter Cassegrainian telescope that was aimed vertically downward.

Oscilloscopic traces of the signal reflected from the sea surface and the ocean floor could either be recorded by a movie camera on 35 mm film or digitized into 500 discrete channels of information and stored on magnetic tape, from which depth information could be extracted. An aerial color movie camera recorded the geographic footprint while a boat crew of oceanographers measured depth and other relevant water parameters.

About two hundred hours of flight time on the NASA C-54 airplane in the area of Chincoteague, Virginia, the Chesapeake Bay and in Key West, Florida, have yielded information on the actual operating conditions of such a system and helped to optimize the design. One can predict the maximum depth attainable in a mission by measuring the effective attenuation coefficient in flight. This quantity is four times smaller than the usual narrow beam attenuation coefficient.

Several square miles of a varied underwater landscape

have also been mapped. Such a system can be either used alone in a scanning device or in conjunction with aerial photography to serve as reference. In either case, it promises great savings in time and expense over the usual sounding techniques.

Eight, Experimental, Significant.

Chincoteague, VA., Chesapeake Bay and Key West, Florida; December 1973 - March 1975.

Laser Bathymeter (a pulsed neon laser and a frequency-doubled Nd:YAG transmitter).

Remote sensing, Airborne laser bathymeter, Fluorescence, Hydrographic chart, Space oceanography.

Author's Conclusions (Modified) - In practice, the use of the Airborne Laser Bathymeter is limited to shallow coastal waters, due to the moderate losses experienced underwater by a light beam.

The Airborne Laser Bathymeter is ultimately limited by noise. The background level has contributions from atmospheric light and sea surface modulation.

This technical note compiles the results of the authors' 15 month period of development and test efforts.

Kim, H.H. and G.D. Hickman*, (September 1973), "An Airborne Laser Fluorosensor for the Detection of Oil on Water", Proceedings of the Use of Lasers for Hydrographic Studies, pp. 197-202. NASA-Wallops Station, Virginia; Sparcom Inc., Alexandria, Virginia.*

Abstract - An airborne laser fluorosensor for the detection of oil derivatives on water has been tested. The system transmits 337 nm U.V. radiation at the rate of 100 pulses per second and monitors fluorescent emission at 540 nm. Daylight flight tests were made over the areas of controlled oil spills and additional reconnaissance flights were made over a 50 km stretch of the Delaware River to establish ambient oil baseline in the river. The results show that the device is capable of monitoring and mapping out extremely low level oil on water which cannot be identified by ordinary photographic method.

Five, General Review, Significant.
Coast of Virginia, May 1973.
Laser Fluorosensor (transmits at 337 nm and receives at 540 nm).
Remote sensing, Laser fluorosensor, Fluorescence, Oil spills, Oil pollution, Detection.

Comments - The authors report the successful operation of an airborne laser fluorosensor system which was designed to detect and map surface oil, either natural seepage or spills, in large bodies of water. This report reviews the tests undertaken and significant results that lead to the above conclusions.

Klemas, V., (September 1972), "Detecting and Measuring Oil on Water", Instrumentation Technology, pp. 54-59. University of Delaware. CCRS # 1015546.

Abstract - Any difference in the properties of oil and water offers a potential method for detecting pollution. Successful detectors can discriminate among different oil types and are not confused by other pollutants which may resemble oil. A group of detectors which have had some success is examined from the viewpoints of the effects exploited and how much information can be delivered.

Fourteen, General Review, Significant.

Floating monitor, Photomapping techniques, Radiometric methods, Radar.

Oil pollution, Detection, Remote sensing, Remote sensors.

Comments - The author concludes; under ambient conditions, the floating reflectometer is ideally suited for monitoring oil layers near the surface (in quantities greater than 0.1 in). Reflectance photography provides a mapping technique if more sophisticated methods are unobtainable. Thermal IR and microwave radiometry are able to detect and estimate thickness of oil slicks under day or night conditions. Radar offers an all-weather rapid mapping capability, however the fluorescence technique may yet be preferred to detect oil under night conditions.

Klemas, V., (September 1973), "Requirements for Airborne Laser Systems Used in Coastal Studies", Proceedings of the Use of Lasers for Hydrographic Studies, Wallops Island, Virginia, pp. 35-46. University of Delaware.

Introduction - One of our investigations in the Delaware Bay region, sponsored by the Office of Naval Research Geography Programs, requires the use of airborne lasers for wave profiling. Several other studies could definitely be enhanced by introduction of active remote sensors, such as lasers. In this paper, I intend to review the requirements for airborne laser systems to be used for the following applications:

a. Photo-optical determination of shallow water wave spectra.
b. Bathymetry in highly turbid waters.
c. Chlorophyll concentration monitoring.
d. Oil dispersion mapping.

As will be shown, each of these applications would provide solutions to environmental and ecological problems eagerly sought by national and regional agencies.

Eighteen, General Review, Normal.
Delaware Bay Region.
Remote sensing, Laser systems, Coastal studies, Fluorescence.

Comments - A laser fluorosensor can be used to map the chlorophyll concentration in the water and quantify it in terms of plankton and detritus.

The airborne laser fluorosensor for the remote measurement of algae (phytoplankton) and chlorophyll in the sea has been successfully operated over test areas of Lake Ontario.

The airborne laser fluorosensor for the detection of oil derivatives on water has been successfully tested by NASA.

The system transmits 337 nm U.V. radiations at the rate of 100 pulses per second and monitors fluorescence emission at 540 nm.

Kondratyev, K.Y., A.A. Buznikov, D.V. Pozdnyakov, G.A. Ivanyan, G.A. Lakhtanov, V.M. Orlov and S.M. Mikhailova, (April 1974), "The Application of Spectrometric and Polarization Techniques for Remote Sensing of Oil on Sea Water", Proceedings of the Ninth International Symposium on Remote Sensing of Environment, Vol. III, pp. 1793-1802. University of Leningrad, Leningrad, USSR. CCRS # 1005084.

Abstract - The paper presents the results of the investigations made over the water area with the purpose of (a) obtaining complex data on the optical properties of the sea surface polluted by an oil film, and (b) working out recommendations for remote sensing. The apparatus installed on-board the helicopter includes a hand-held spectrograph RSS-2, a polarimeter and two cameras operating in four spectral regions. Both the spectrograph and cameras are provided with polarization attachments. The measurements were conducted in the wavelength range of 0.4 to 0.8 μm at heights up to 200 m.

As a result, data have been obtained on spectral brightness distribution and the degree of polarization of the radiative flux at different heading angles relative to the sun and at various viewing angles for the cases of the clean and polluted sea surface. The optimal spectral intervals and polarization regimes which ensure the most contrasting photographic images of oil films have been determined. A discussion of the results is given.

Eighteen, Experimental and General Review, Significant.

Caspian Sea; September-October 1973.

Polarimeter and cameras.

Remote sensing, Oil pollution, Sea water, Spectrometric, Polarization.

Author's Conclusions - The results discussed in the paper show that the problem of remote detection of oil slicks may be solved, in principle, by using optical methods. The pressing problem is to find the most effective technique and to develop the instrumentation fit for the operational application. The first steps in this direction have been made. Yet, many aspects of the problem require further development. For successful solution of the problem of remote detection of oil spills careful laboratory investigations are needed. They will give the opportunity to compile a catalogue of optical properties of different types of oil and oil products in various stages of their degradation under natural conditions. Attempts should be made to find stable correlations between the thickness of an oil slick, its composition and optical contrasts under different conditions of illumination and sea state.

For space (satellite) remote sensing account should be taken of the intermediate atmospheric thickness (4, 18). In this connection it is very important to determine the atmospheric transfer function (18) which will allow the spectral characteristics obtained from space or high-altitude aircraft to be transformed on the level of the underlying surface.

All this will undoubtedly permit in the near future the development of effective remote techniques for detection and characterization of contaminated water areas.

Kraus, S.P., J.E. Esks, S.G. Atwater, J.R. Jensen* and R.R. Vollmers**, (December 1977), "Radar Detection of Surface Oil Slicks", Photogrammetric Engineering and Remote Sensing, Vol. 43, No. 12, pp. 1523-1531. University of California, Santa Barbara, CA.; University of Georgia, Athens, GA.*; U.S.C.G., Washington, D.C.**. CCRS # 1015011.

Abstract - The United States Coast Guard currently is developing AIREYE, an all-weather, day/night airborne surveillance system, for installation aboard future medium range surveillance (MRS) aircraft. As part of this program, a series of controlled tests was conducted off southern California during May, 1976 in order to evaluate the oil slick and surface target detection capabilities of two Motorola-developed side-looking radars. The systems, a real-aperture AN/APS-94-D and a synthetic-aperture coherent-on-receive (COR), were flown over the Santa Barbara Channel on May 19, 1976. Targets imaged during the coincident overflights included natural oil seepage, simulated oil spills, oil production platforms, piers, mooring buoys, commercial boats and barges, small pleasure craft, and coastal kelp beds. This paper describes the test program and compares oil and surface target detection results for the two systems. Based on an analysis of imagery from the coincident radar runs, COR provided better detection of natural and man-made oil slicks, whereas the AN/APS-94-D consistently exhibited higher surface target detection results.

Ten, Experimental and General Review, Significant.

Santa Barbara Channel, California; May 19, 1976.

Two Motorola SLAR's; Real-aperture AN/APS-94-D and Synthetic Aperture Coherent-on-receive (COR).

Remote sensing, Detection, Radar, Oil slicks, Oil pollution.

Comments - The conclusions of this experiment are in the form of a comparison between the two types of radar. Significant results included; the AN/APS-94-D system detected man-made targets (fixed or moving) from a variety of look directions and ranges significantly better than the COR system. The COR system detected surface concentrations of oil significantly better than the AN/APS-94-D system. Target returns on AN/APS-94-D imagery were judged by interpreters to be significantly sharper and more interpretable than those on COR. COR often merged closely spaced targets thus there was a failure to discriminate individual targets from other background returns.

Kriebel, A.R., (November 1973), "Development of a Floating
Oil Slick Detector", U.S.C.G., Washington, D.C., 131
pages. URS Research Company, San Mateo, CA. Report
No. CG-D-42-72.

Abstract - This report describes a series of laboratory tests aimed at the initial development of a floating oil slick detector. In principle the detector operates like a viscometer, with a cylinder spinning inside a slightly larger cylindrical shroud partially submerged in the water surface. An oil slick causes the spinner to become coated with oil (rather than water) so that the shaft torque and the electrical current through the drive motor both increase. The increased current can be used to close a relay and thereby signal the presence of floating oil.

The test data reported include the recorded variations of motor current for four types of oil, three oil slick thicknesses, and ten different spinner-shroud configurations. The effects of floating debris particles, debris filters, simulated wave motion, and different spinner materials were also tested. The effects of submerging the detector, cycling if on and off, and cycling it forward and reverse were also studied to determine whether the corresponding transients in the motor current might be used to indicate the various types and thicknesses of oil slicks.

The test results indicate that all the oil slicks are readily detected by most of the spinner-shroud configurations, and that there is also a limited capability to discriminate the types and thicknesses of oil slicks.

Nil, Experimental and General Review, Normal.
Floating oil slick detector.
Detection, Oil slick, U.S.C.G.

Comments - Test results are presented and described for ten different slick detector configurations, for four different types of oil slicks, and for three different slick thicknesses and the conclusions drawn are presented.

Landers, R.W. and H.V. Johnson*, (April 1978), "Photo Interpretation Keys for Hazardous Substances Spill Conditions", *1978 National Conference and Exhibition on Control of Hazardous Material Spills*, Miami Beach, Florida, 14 pages. Environmental Protection Agency, Las Vegas, Nevada; Lockheed Electronics Company, Inc., Las Vegas, Nevada*. CCRS # 1018878.

Abstract - The EPA's Environmental Monitoring and Support Laboratory in Las Vegas is producing photo interpretation keys which are aerial photographic examples of hazardous substances spills and potential spill conditions within typical chemical processing and storage facilities. Color aerial photography, acquired over a variety of chemical processing facilities along the Lower Delaware River Estuary and the Baltimore Harbor area, provides the primary source of data for the keys. Typical in-plant facilities covered by the keys include: (1) product storage facilities, including storage and holding tanks and dry product stock piles; (2) product transfer facilities, such as marine and river terminals, tank car and truck racks, in-plant pipe lines, and conveyors; and (3) plant drainage and wastewater treatment facilities. The keys are designed to aid both experienced remote sensing specialists and EPA Regional oil and hazardous substances spill prevention and control personnel in monitoring chemical facilities for compliance with anticipated spill prevention regulations to be issued under authority of the Federal Water Pollution Control Act (FWPCA) as amended in 1977.

Four, General Review, Normal.
Lower Delaware River Estuary.
Colour Aerial Photography.

Remote sensing, Aerial photography, Photo interpretation keys, Hazardous substances, Oil pollution.

Author's Summary (Modified) - A significantly large proportion of any hazardous material production and storage structures can be photographed from the air, and many facilities can be photographed in a single day. Color film is well suited for recording the presence and structural integrity of secondary containment structures, for idenfifying product spills, stains and vegetation damage resulting from product spills, and for recording evidence of spillage and leakage entering nearby water bodies.

Lapp, P.A., (August 1975), "An Investigation of Systems for the Surveillance and Monitoring of Oil Spills at Beaufort Sea", Canada Centre for Remote Sensing, Ottawa, Ontario, 72 pages plus appendices. Philip A. Lapp Ltd., Toronto, Ontario. CCRS # 1015983-1015986.

Introduction (Modified) - This study was undertaken at the request of CCRS and the objective is to investigate methodologies for the detection and clean-up of oil which may be released as a result of exploration activities in the Beaufort Sea.

Philip A. Lapp Ltd. was contracted to undertake a portion of this investigation, "to evaluate and develop a scenario of remote sensing methods and procedures of oil spills in the Beaufort Sea under three separate conditions; a) 100% ice cover (no open water); b) ice infested waters; c) totally ice free water."

Study was later expanded to encompass, "the investigation of systems for the surveillance and monitoring of oil spills at the Beaufort Sea".

Nil (Appendix C; fifteen), General Review, Highly Significant. Beaufort Sea; December 1972 to March 1975.

Comments - The author of this paper evaluated several technologies including the supporting logistics and skills required, and concluded that the following instruments could be incorporated into a system to be tasked with the role of surveillance and monitoring of oil spill in the Beaufort Sea;

Remote Sensing Package (light aircraft)

- thermal IR line scanner
- L^3TV

Remote Sensing Package (Major)
- SLAR
- Thermal IR line scanner
- L^3TV

Ice Coring Program
- Ice augers
- Gas analyzers

Leigh, J.T. and C.C. Bates, (1978), "Current U.S. Coast Guard Technological Developments Relative to the Detection, Control, and Clean-up of Oil Spills", International Oil-Pollution Prevention Exhibition and Conference, Hamburg, Germany, pp. 55-74. Office of Research and Development, U.S.C.G., Washington, D.C.

Introduction - The present high degree of public and political interest in having an adequate oil spill control technology dates largely from spills caused by the Torrey Canyon (1967) and the Platform "A" off Santa Barbara, California, USA in 1969. This interest has been rekindled by the Argo Merchant (1976), the North Sea Platform "B" (1977) and the Amaco Cadiz (1978) spills of the past two years. In the U.S., the Federal Water Pollution Control Act of 1970, as amended in 1972 and 1977, permitted the Federal Government to develop a comprehensive oil spill control program involving mandatory reporting and clean-up, contingency plans, strike forces, a national pollution clean-up fund, and an extensive research, development, test, and evaluation program to provide improved technology and techniques for handling such spills.

Within the U.S. Federal establishment, the Coast Guard has specialized in the control and clean-up of oil spilled into the nation's major waterways and the coastal zone. In order to enhance this capability over $21 million U.S. dollars have been expended by the Coast Guard in research, development, testing and evaluation between 1968 and the present. The attached list of references is representative of technical reports published which document this work in great detail. A complete listing of the 200 plus reports which have been published is available by request. The following is a brief overview of the major equipment and systems which are in the prototype stage or are already operational as a result of this program.

Thirteen, General Review, Significant.

Sidelooking radar (modified APS/94D system), IR/UV line scanner (8 to 14 μm and 0.32 to 0.38 μm), Camera, Passive microwave imager (37 GHz).

Remote sensing, Oil spills, Detection, Control, Clean-up, Microwave, Ultraviolet, Infrared, Sensors.

Author's Summary (Modified) - The experience gained during the development and testing of the systems discussed above and during the response to oil spills under a wide range of conditions has clearly indicated the need for continued research and development efforts in various areas. These include, 1) control and recovery of spills in high currents, 2) high-volume, high viscosity tanker offloading systems, 3) development of high-volume flaring disposal techniques and lightweight incinerators, 4) high viscosity oil recovery and transfer equipment, 5) in-tank oil immobilization, 6) plugging and patching techniques, 7) temporary storage capacity, 8) equipment mooring systems, 9) oil slick burning, and 10) oil slick movement and dispersion studies. Brief discussion of current efforts in a few of these areas follows.

MacDowall, J. and B.H. Nodwell, (May 1971), "Study of Sensors for Earth Resource Satellites and Airborne Remote Sensing", Dept. of Energy, Mines and Resources, Canada, Ottawa, Ontario, 178 pages. Centre for Applied Research and Engineering Design, McMaster University, Hamilton, Ontario.

Introduction (Modified) - The objective of the study is to compile a comprehensive compendium of all the significant physical characteristics of remote sensors, together with some sketches illustrating their method of operation. This information will be helpful in selecting the most appropriate available system for use, and will also guide sensor development into those areas not covered by existing systems. The tables are arranged in such a way that comparison of characteristics between sensors is easily made. A brief introduction of each class of sensors is given, together with a brief description of each system. The intention is to give the reader an introduction to the physical basis of each sensor and facilitate comparison with other systems.

Nil, General Review, Significant.

UV, Visible, IR and Microwave Sensors.

Remote sensing, Airborne systems, Satellite systems, Manufacturers.

Comments - For each of the major types of systems, a detailed questionnaire was drawn up and then sent to sensor manufacturers and developers. One hundred and thirty eight questionnaires were mailed and replies were received from twenty six manufacturers and developers in the United States, twelve in Canada and three in England. A literature search of published works was also undertaken. This report is a compilation of the above responses and searches.

Mann, J.R., (February, 1979), "Detection of Oil Trapped
Under Ice Using Impulse Radar, Phase II Report", Esso
Resources Canada Limited, Calgary, Alberta, 16 pages.
Geophysical Survey Systems, Inc., Hudson, New Hampshire.
CCRS # 1034425; APOA No. 119.

Introduction - Geophysical Survey Systems, Inc. (GSSI) has participated with the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) to perform a series of tests to determine the feasibility of using field type impulse subsurface radar equipment to detect the presence of a layer of oil under a sheet of sea ice. Artificial sea ice was grown in a large tank at the CRREL facility and oil injected under the ice. GSSI radar equipment was used to acquire data from the ice surface before and after the oil injection. The GSSI principal investigator was John Mann and the CRREL principal investigator was Arnold Dean.

The goal of this project is to develop methods for using radar to detect relatively thin layers of oil under sea ice, and to demonstrate the effectiveness of these methods by testing under similar conditions. This report describes two radar configurations that show theoretical promise of detecting oil, the ice growing equipment and technique, and the results of the radar tests on the ice. In spite of the difficulties encountered in obtaining the desired characteristics, the tests have been encouraging. High frequency (700 MHz) radar signals have successfully penetrated 2 feet of ice and thus can be used to provide good resolution for the sensing of thin oil layers. Test results with oil present were obtained only for the case of very uneven oil thickness, but showed a strong change in the radar signal due to oil.

Nil, Theoretical and Experimental, Normal.
CRREL Laboratory, Hanover, New Hampshire.
Impulse Subsurface Radar.
Remote sensing, Oil, Sea ice, Radar, Detection.

Author's Conclusions - Despite the problems with ice properties and shape, the tests to date have given an indication that detection of thin oil layers under ice may be possible. It has been possible to probe through ice with a thickness of up to two feet with the 101 antenna operating at a center frequency of 700 MHz. The successful use of a high frequency allows adequate resolution to be obtained. Vertical probing tests have indicated that oil layers of about 5 inch thickness or greater can be detected. More sophisticated deconvolution processing of the data may reduce the detectable thickness to around 2 inches. A test technique using polarization effect was developed and tried. Although large changes in polarization were observed when wedges of oil were present under ice, the technique cannot be considered verified until further tests are made with uniform oil layers.

Maurer, A.T., A.T. Edgerton* and D.C. Meeks*, (1977), "U.S. Coast Guard Airborne Oil Surveillance System Status Report", Proceedings of the 11th International Symposium on Remote Sensing of the Environment, Ann Arbor, Michigan, II, pp. 1639-1640. U.S. Coast Guard, Washington, D.C.; Aerojet ElectroSystems Company, Azusa, California.* CCRS # 1014661.

Abstract - Evaluation of a U.S. Coast Guard prototype operational airborne coastal patrol system has been completed. The prototype system has proven effective for detection, monitoring, and assessment of offshore oil discharges; search and rescue operations; ice reconnaissance; and monitoring of foreign fishing activities in coastal waters. The system combines several sensors (side-looking radar, IR/UV line scanner, camera and passive microwave imager) with a real-time display system for effective operation around the clock and under all but extreme weather conditions. The Coast Guard subsequently contracted with Aerojet ElectroSystems Company to modify the sensor equipment for installation in a C-130 aircraft for operational deployment. Active operations using the modified system are scheduled to begin in January 1977. This paper describes the results of prototype operational evaluation, the operational configuration of the C-130 system, and the future plans for the system.

Two, General Review, Significant.

California Coast; 1975 and 1976.

Line Scanner, Low Light Level TV, Passive Microwave Imager and Mapping Radar.

Remote sensing, Oil pollution, Surveillance, United States.

Comments - This paper reviews the AOSS prototype system. A general description of the Background, Operational Evaluation, System Description and Future Plans are included.

Measures, R.M., (September 1973), "Lidar Programs in Canada", Proceedings of the Use of Lasers for Hydrographic Studies, Wallops Island, Virginia, pp. 27-34. University of Toronto.

Introduction (Modified) - Canada is a vast country and within her borders lies the largest supply of fresh water in the world. It is therefore natural for airborne hydrographic probing to be regarded as a vital part of her resource surveillance program. Indeed, some three years ago, the Canada Centre for Remote Sensing was created to coordinate the data collection from both aircraft and satellite sensors. Even before the Canada Centre for Remote Sensing was created, Dr. L.W. Morley, the first Director of the Centre, initiated an exploratory program to stimulate new sensor development. This farsighted approach has been reasonably successful; for within this short space of time, three hydrographic LIDAR groups have emerged within Canada.

Nil, General Review, Significant.
Laser Radar Systems.
Remote sensing, Laser radar systems, Canada.

Author's Summary - In Canada there are three hydrographic LIDAR groups and their current activities can be classified along three main lines of attack; laser induced fluorescence, Raman scattering and laser extinction measurements. In several areas, both field and flight trials are either underway or currently planned and the results so far obtained have been encouraging and are likely to stimulate further work in the future, depending on user requirements.

Meeks, D.C., J.J. Bommarito, R.S. Schwantje and A.T. Edgerton, (August 1977), "Transfer, Installation and Flight Testing of the Modified Airborne Oil Surveillance System (AOSS II) in a HC-130B Aircraft, Final Report", United States Coast Guard, Washington, D.C., 161 pages. Coast Guard - D-60-77.

Abstract - The prototype airborne oil surveillance system (AOSS I) developed for the U.S. Coast Guard by Aerojet ElectroSystems under Contract DOE-CG-22170A was modified and transferred from a HU-16 aircraft to a HC-130B aircraft. The added capabilities of the new system configuration were verified by a flight test program.

Modifications to the system included (1) the addition of a high resolution aerial reconnaissance camera, (2) the addition of a dual look (left and right) capability for the SLAR, (3) automatic SLAR target position location, (4) an airborne remote temperature measurement capability, (5) simultaneous multispectral recording capability for the IR-UV line scanner data, and (6) improved processing of passive microwave imager data.

The proven system capabilities of AOSS I combined with the added capabilities incorporated into AOSS II provide a unique and valuable system to support all U.S. Coast Guard missions. The system is currently operational and based at Elizabeth City, North Carolina.

Three, Experimental and General Review, Highly Significant.

California coast; March 1976 to July 1977.

SLAR; Passive Microwave Imager (PMI), Line Scanner, KS-72 Camera, Data Processing Console, SLAR Equipment Rack, Power Supply Rack, and a LTN-51 Inertial Navigation System.

Coastal surveillance, Remote sensing.

Author's Comments (Modified) - This document provides details of improvements to the U.S. Coast Guard Airborne Oil Surveillance System (AOSS), installation of the system aboard U.S. Coast Guard HC-130B aircraft No. 1347 and subsequent flight evaluation of the improved AOSS equipment (AOSS II).

Modifications to the AOSS equipment are summarized. The HC-130B installation was configured to preserve multimission utility of the aircraft with minimal effect on the aircraft center of gravity, flight characteristics, and cargo payload.

Details of the improvements and installation of the AOSS II hardware are described and are summarized. Recommendations for several improvements to increase operational effectiveness of AOSS II are given based on the flight evaluation and subsequent operational deployment of the system.

Meeks, D.C., D.P. Williams, R.M. Wilcox and A.T. Edgerton, (March 1971), "Microwave Radiometric Detection of Oil Slicks", U.S. Coast Guard, Applied Technology Division, Washington, D.C. 102 pages. Aerojet-General Corporation, El Monte, CA.

Abstract - Two years of research have been conducted to determine the feasibility of using microwave radiometry for the detection, identification, and surveillance of oil pollution. The research can be divided into three main areas: (1) theoretical studies, (2) laboratory experiments, and (3) airborne measurements. Theoretical studies consisted of a review of contemporary theory concerning parameters that influence microwave emission from both unpolluted and oil-covered areas. Laboratory investigations confirmed results obtained from earlier studies and established the response characteristics of the 3.2-mm sensor to continuous oil films. Airborne measurements of controlled spills off the Southern California Coast were performed with dual-polarized 3.2- and 8.1-mm sensors oriented with a forward antenna viewing angle 45° above nadir. Four sets of oil spills, or missions, were performed to obtain data over a variety of sea-surface conditions. Pollutants used for the tests included No. 2 diesel fuel, 26.1 and 21.6 API gravity crude oils, and 9.7 API gravity fuel oil. For each set of spills, both ocean surface observations and airborne measurements were performed for three days, or until the slicks dissipated. Significant microwave brightness temperature oil slick signatures were noted for a wide range of ocean conditions (sea states 1-4) and oil film thickness (thickness <1 micron and greater). Based on the experimental results a passive microwave imaging system configuration has been recommended for oil pollution surveillance.

Thirty four, Theoretical and Experimental, Significant.

Southern California Coast; Fall 1970.

Dual polarized 3.2 and 8.1 mm radiometer, 35 mm framing camera and a K-17 nadir-looking areal camera.

Remote sensing, Microwave, Oil spills, Oil slick, Radiometer, Areal camera, California coast.

Author's Conclusions (Modified) - The Southern California controlled oil spill experiment, combined with the supporting laboratory and theoretical research concerning the microwave emission characteristics of oil films have yielded the following results:

- Oil slicks on the ocean surface provide unique and readily measurable signatures. Signatures ranging up to 70°K were noted while overflying thick portions of oil slicks. All slicks encountered during the controlled oil spills contained thick portions that were detectable.
- The microwave emission characteristics of oil slicks vary with oil type and film thickness. The mass of oil per unit area is the parameter of most importance.
- The microwave emission characteristics of oil slicks vary with sea state, and provide measurable signatures over a wide range of sea-state conditions. Oil films with an average thickness of one μm were readily detected with 3.2- and 8.1-mm sensors.
- Both theory and measurements demonstrate that horizontally polarized sensors are more responsive to oil films than vertically polarized sensors.
- The microwave brightness temperature signatures of oil slicks increase with sensor frequency (vary inversely with sensor wavelength). However, atmospheric attenuation also increases with frequency.

- The available atmospheric and oil film signature data indicate that a frequency (wavelength) of about 37 GHz (8.1 mm) is optimal.

These results indicate that imaging microwave radiometers can be employed to detect and map oil slicks.

Millard, J.P., J.C. Arvesen and P.L. Lewis, (March 1975), "Development and Test of Video Systems for Airborne Surveillance of Oil Spills", Department of Transportation, U.S.C.G., Washington, D.C., 25 pages. Ames Research Center, NASA, Moffett Field, CA. Report No. CG-D-95-75.

Abstract - Five video systems - potentially useful for airborne surveillance of oil spills - were developed, flight-tested and evaluated. The systems are: (1) conventional black and white TV; (2) conventional TV with false color; (3) differential TV; (4) prototype Lunar Surface TV; and (5) field-sequential TV. Wavelength and polarization filtering were utilized in all systems.

Greatly enhanced detection of oil spills, relative to that possible with the unaided eye, was achieved. The most practical video system is a conventional TV camera with silicon-diode-array image tube, filtered with a Corning 7-54 filter and a polarizer oriented with its principal axis in the horizontal direction. Best contrast between oil and water was achieved when winds and sea states were low. The minimum detectable oil film thickness was about 0.1 micrometer.

Nil, Experimental and General Review, Highly Significant.

Southern California Coast; Fall 1970.

Video Systems; 1) Conventional B&W TV, 2) Conventional TV with false colour, 3) Differential TV , 4) Prototype Lunar surface TV, 5) Field-sequential TV.

Oil slicks, Environmental pollution, Remote sensing.

Author's Conclusions (Modified) - Significant finds of this study are: (1) greatly enhanced detection of oil spills, relative to that possible with the unaided eye, can be achieved with TV systems; (2) this enhanced detection can be achieved with an inexpensive, conventional TV camera, filtered and displayed on a black and white monitor; (3) expensive UV transmitting optics are not required; (4) this enhanced detection was always achieved in tests over natural slicks if the seas were calm; (5) false-color enhancement can be performed with good results under overcast skies but a problem of nonuniformity in signal, caused by sun glint on clear days, remains to be solved; (6) the differential technique minimizes this sun glint problem; (7) the two-camera differential technique does not offer sufficient gains in contrast, relative to a one-camera system, to compensate for alignment problems; (8) the field-sequential system requires further development and flight test; (9) a major problem with video systems, and one that merits further attention, is that the dynamic range of brightness in a water scene is often larger than the video system can accommodate; and (10) a silicon-diode-array tube, adjusted for water viewing, will often "bloom" when viewing a bright object such as a boat or land.

With an appropriately filtered black and white system, oil is almost always displayed as a bright white against a dark water background. Exceptions occur when oil thicknesses are less than about 0.1 micrometer and when viewing in a direction where water, rather than oil, specularly reflects light to the TV camera.

Future courses and recommendations are outlined.

Millard, J.P. and G.F. Woolever*, (1974), "Video Detection of Oil Spills", U.S. Coast Guard, 18 pages. Ames Research Center, NASA, Moffett Field, California; USCG-Headquarters, Washington, D.C.* Coast Guard MIPR Z-70099-2-23146; CCRS # 1008712.

Abstract - Three airborne television systems are being developed to evaluate techniques for oil-spill surveillance. These include a conventional TV camera, two cameras operating in a subtractive mode, and a field-sequential camera. False-color enhancement and wavelength and polarization filtering are also employed. The first of a series of flight tests indicates that an appropriately filtered conventional TV camera is a relatively inexpensive method of improving contrast between oil and water. False-color enhancement improves the contrast, but the problem of sun glint now limits the application to overcast days. Future effort will be aimed toward a one-camera system. Solving the sun-glint problem and developing the field-sequential camera into an operable system offers potential for color "flaging" oil on water.

Fourteen, General Review, Significant.
Santa Barbara Channel.
Television camera systems.
Remote sensing, Television, Detection, Oil spills.

Comments - The three basic systems evaluated in this paper were; a Conventional TV Camera / Black & White or False Color, a Two Camera System / Black & White or False Color and a Field Sequential System. The designs and techniques associated with these cameras are outlined, discussed and the significant results are presented.

Neville, R.A., V. Thomson, K. Dagg* and R.A. O'Neill**, (1979), "An Analysis of Multispectral Line Scanner Imagery from Two Test Oil Spills", *Proceedings of the First Workshop Sponsored by Working Group I of the Pilot Study on the Use of Remote Sensing for the Control of Marine Pollution,* sponsored by the NATO Committee on the Challenges of Modern Society, Washington, D.C., 15 pages. Intera Environmental Consultants Ltd., Ottawa, Ontario; The Genesys Group*; Canada Centre for Remote Sensing, Ottawa, Ontario**. CCRS # 1028048.

Abstract - Results of flights of a Daedalus model 1260 multispectral line scanner and a Daedalus model 1230 infrared/ultraviolet line scanner over two test oil spills off the New Jersey coast are reported.

The Daedalus multispectral scanner has 10 channels in the spectral range of 0.38 to 1.1 μm and an eleventh in the thermal infrared from 8.5 - 12.5 μm. A rotating mirror covers a scan angle of 85.9° with an instantaneous field of view of 2.5 mrad. High contrast imagery of the oil slick was obtained in the thermal infrared channel. Images of the oil spill in the near infrared channels showed only the thicker regions of the oil slick and these with less contrast than was apparent in the thermal infrared channel. Imagery from successively shorter wavelength channels showed a larger area slick, corresponding to the thinner outer boundaries. The area of the slick observed in the 0.70 - 0.79 μm band was nearly equal to that in the 8.5 - 12.5 μm band. Sun glitter from the sea surface can degrade the imagery in all but the thermal channel though it was observed to be slightly reduced in the blue channels (wavelength less than 0.5 μm).

The Daedalus model 1230 dual channel line scanner was also flown over the test oil spills. It was fitted with a thermal infrared detector (8.5 - 12.5 μm) and an ultraviolet detector (0.27 - 0.37 μm). This scanner has a 77.3° scan angle with a 2.5 mrad instantaneous field of view. The thermal infrared imagery obtained with this scanner was identical to that obtained with the multispectral scanner.

Two techniques were used to display the data from the UV and IR channels. The first was simply to colour density slice the data from each channel separately and to overlay the two images. In the second approach, for each pixel in the image, the pair of intensity values; (one the UV, the other the IR), plotted in a 2 dimensional vector space. The points in this spectral space are grouped into clusters containing nearest neighbours, and to each cluster a colour is assigned. Each image pixel represented by a point in a given cluster acquires the cluster's colour, thereby producing a thematic image in which the themes correspond to oil films of different thicknesses. Though this produced essentially the same image as was obtained by the simple photographic overlay technique, it may be of value in the development of data acquisition systems or real time displays for this type of data.

Fourteen, General Review, Significant.

New Jersey Coast, November 2nd and 3rd, 1978.

Daedalus model 1260 multispectral line scanner and Daedalus model 1230 infrared/ultraviolet line scanner.

Remote sensing, Multispectral line scanner, Test sites.

Author's Conclusions - It must be concluded that as far as the extent and the relative thickness of the slick is concerned, the UV and thermal IR together provide virtually all the information available in the whole spectral region including UV, visible, near IR, and thermal IR. Hence for airborne remote sensing a UV-IR line scanner provides an attractive method for oil detection. For higher altitudes and satellite platforms, the UV would be seriously plagued by atmospheric scattering and path radiance. Under these circumstances, a longer wavelength, between 400 nm and 650 nm, would be preferable.

North, D.M., (December 1982), "Integrated Sensors Used in Surveillance", Aviation Week and Space Technology, Dec. 6, page 136. CCRS # 1037194.

Introduction (Modified) - The Swedish Coast Guard is operating a multisensor integrated system, to perform its maritime surveillance missions. The capabilities of the remote sensing systems mounted in the twin-piston-engine general aviation aircraft were demonstrated to the Aviation Week and Space Technology editor during a flight from Bromma Airport.

Nil, General Review, Normal.

Comments - The oil surveillance system presently operated by the Swedish Coast Guard is outlined in this article. A general overview of the system operations, cost, sensors and future plans are given.

NTIS, (1982), "Oil Pollution Detection and Sensing", National Technical Information Service, Springfield, VA., 232 pages, NTIS # PB82-805797.

Introduction - NTIS searches are online information products developed from the NTIS data base, which contains more than 750,000 document/data records of Government-sponsored research. NTIS provides two types of NTI searches: published searches and customized online searches.

Published searches are bibliographies with abstracts that provide a quick, inexpensive way to determine which reports in the NTIS data base are of special interest to a user. The searches are prepared by NTIS information specialists and are available in many topic areas, they are updated at regular intervals and cost $30 each. The cost of a published search will be credited toward the cost of a customized online search in the event the published search does not meet ones needs. A complete list of current published searches is available free by requesting brochure number NTIS-PR-186.

If your needs are more specialized and you want a custom online search, please write to NTIS or call the online search telephone number (703) 487-4642, to discuss specific areas of interest with an information specialist.

Two hundred and thirty two, Bibliography, Highly Significant.
Remote sensing, Bibliography, Oil pollution, Detection.

O'Neil, R.A., L. Buja-Bijunas and D.M. Rayner*, (March 1980), "Field Performance of a laser fluorosensor for the detection of oil spills", Applied Optics, Vol. 19, No. 6, pp. 863-870. Canada Centre for Remote Sensing, Ottawa, Ontario; National Research Council, Ottawa, Ontario*. CCRS # 1022671.

Abstract - An airborne laser fluorosensor is described that was designed to detect and identify targets by means of the characteristic fluorescence emission spectrum. The first field trials of the sensor over marine oil and dye spills are reported. A correlation technique has been developed that, when applied to the data collected during these field trials, clearly differentiated among dye, the two crude oils, and the general fluorescence background of ocean water.

Ten, General Review, Highly Significant.

New Jersey Coast, 1978.

Laser Fluorosensor (337 nm).

Remote sensing, Detection, Oil spill, Laser fluorosensor, Fluorescence.

Comments - The field trials showed the laser fluorosensor capable of detecting oil in a marine environment. This paper dealt exclusively with the detection of oil by the fluorosensor. The sensor will continue to be tested over oil spills, where the authors predict that it will provide the capability of classifying oils as light, crude or heavy.

O'Neil, R.A., R.A. Neville* and V. Thomson*, (June 1980), "The Recommended Remote Sensing System for the Detection and Tracking of Oil Spills in Canada", Arctic Marine Oilspill Program, Technical Symposium, Edmonton, Alberta, 18 pages. Canada Centre for Remote Sensing; Intera Environmental Consultants Ltd.*, CCRS # 1023217.

Abstract - As a result of four separate remote sensing experiments carried out to determine the optimum techniques for the tracking and detection of oil in ice infested waters, it is now possible to recommend the system which will be the most effective under the wide variety of conditions experienced in Canada. The sensor complement should consist of the laser fluorosensor, an ultraviolet/infrared line scanner (UV/IRLS), a side looking airborne radar (SLAR), a low light level television (LLLTV) and photographic cameras. These sensors must be supported by a real time data annotation, display and analysis system. Were such a package to be mounted on a suitable aircraft, Canada would have a very effective tool for a wide variety of routine ocean surveillance applications.

Four, General Review, Highly Significant.

Oil spills, Detection, Remote sensing, Laser fluorosensor, UV/IRLS, SLAR, LLLTV.

Comments - Recommended sensors are reviewed, cost, aircraft requirements and additional mission requirements are discussed.

O'Neil, R.A., A.R. Davis, H.G. Gross and J. Kruus, (1975), "A Remote Sensing Laser Fluorometer", Water Quality Parameters, ASTM STP 573. American Society for Testing and Materials, pp. 424-436. Water Science Section, Inland Waters Directorate, Environment Canada, Ottawa, Ontario. ASTM-04-573000-16. CCRS # 1003258.

Abstract - A variety of water quality parameters are accessible to measurement using the technique of fluorescence spectroscopy. These include such measurements as oil, chlorophyll, lignin sulfonate, and dye tracing. The availability of realiable lasers has opened up the possibility of using the fluorescence technique as a water quality analytical tool without being in direct contact with the body of water. For instance, it is possible to monitor oil on water from such remote locations as a bridge, boat, or aircraft. A system based on a helium cadmium laser is described and some experimental results on different materials from various locations are discussed.

Six, Experimental and General Review, Significant.

Ottawa River.

C.W. Helium-Cadmium Laser Fluorometer.

Water quality, Fluorometers, Lasers, Fluorescence, Environmental tests, Remote control.

Comments - The laser fluorosensor discussed here was designed to determine whether it was possible to make fluorometric measurements remotely. The physics of fluorescence, the Fluorosensor and the field trials are discussed in this paper. It was concluded that the laser fluorometer is able to detect chlorophyll and oil. The field trials carried out on a portion of the Ottawa River near Hawkesbury are documented.

O'Neil, R.A., F.E. Hoge* and M.P.F. Bristow**, (May 1981), "The Current Status of Airborne Laser Fluorosensing", *Int. Symp. on Remote Sensing of the Environment*, Proc., 15th, Ann Arbor, Michigan. pp. 379-398. Canada Centre for Remote Sensing; NASA, Wallops Island, VA;* EPA, Las Vegas, Nevada**. CCRS # 1028295.

Abstract - Airborne laser fluorosensors have been used to identify and quantify specific substances in the aquatic environment. It has been shown that the sensor can identify and classify oil films. If the extinction coefficient is known then the thickness of thinner films ($< 20\ \mu m$) may be calculated. The intensity of the water Raman signal is proportional to the water volume sampled by the sensor and hence an effective attenuation coefficient for the water can be calculated. The same Raman measurement provides the normalization necessary to map chlorophyll and dye concentrations using the intensity of their respective fluorescence signatures.

Twenty eight, General Review, Highly Significant.
Remote sensing, Fluorescence signatures, Fluorosensors.

Comments - It has been shown that a laser fluorosensor can be used to identify and classify oil spills. In an ocean surveillance role, the sensor can be used to confirm, unambiguously, that the anomally is indeed oil.

Laser fluorosensor tests operated by NASA, the EPS and CCRS are discussed. The present oil and chlorophyll detection capabilities as well as future improvements and testing necessities are outlined.

O'Neil, R.A., R.A. Neville* and V. Thomson*, (November 1981), "Report of the Arctic Marine Oilspill Program, Remote Sensing Project", Canada Centre for Remote Sensing, and Environmental Protection Service, Ottawa, Ontario., 216 pages. Canada Centre for Remote Sensing, Ottawa; Intera Environmental Consultants Ltd.*, Ottawa.

Abstract - The AMOP remote sensing project was undertaken in order to evaluate the capability of state-of-the-art sensors to detect oil in ice infested waters. This report outlines the experiment plan and results obtained on four remote sensing missions: Montreal Island, Scott Inlet, Wallops Island, Kurdistan. A large data set was collected during these missions; this data set is the most comprehensive collection to date on the remote sensing of oil spills in Canada. Twelve different sensors were used to detect oil; results are presented and sensor performance is evaluated.

Oil detection systems presently in use in Canada and abroad are examined. Recommendations are given for an integrated sensor package together with a real time display system. The recommended sensors include a side looking radar, a UV-IR channel line scanner, a laser fluorosensor, a low light level television and annotated photographic cameras. A real time display system allows operator interaction with the sensors for the presentation of oil spill imagery and analysis. Hard copy can be obtained for presentation to those responsible for oil spill management.

Fifty three, Experimental and Review, Highly Significant.

Montreal Island, Scott Inlet, Wallops Island, and the Kurdistan Oil Spill. 1978-1979.

Laser Fluorosensor, Dual Channel Line Scanner, Side Looking Airborne Radar, Low Light Level TV, Photographic Cameras, etc.

Remote sensing, Oil spills, Arctic region, Remote
sensors, CCRS.

Comments - A comprehensive study covering all aspects of the remote sensing of oil spills. Four case studies were used in conjunction with this report; Montreal Island, Wallops Island, Scott Inlet and the Kurdistan Oil Spill. The report includes, a description of the experimental objectives and design, as well as the role of remote sensing. State-of-the-art operational systems are discussed and specific sensors are recommended. Each sensor is described and its role in the detection and mapping of oil spills on both water and ice are discussed. Results and representative images are included.

O'Neil, R.A., V. Thomson* and R.A. Neville*, (1981), "Remote Sensing of Oil During the Kurdistan Spill", Canada Centre for Remote Sensing, 63 pages. CCRS, Ottawa; Intera Environmental Consultants Ltd.*, CCRS # 1029241.

Abstract - The Canada Centre for Remote Sensing (CCRS) was asked to respond to the breakup of the tanker KURDISTAN, in order to search for and map the oil which was spilled. This report gives a sortie by sortie summary of the flight operation during the mission, along with a discussion of data treatment and image processing. A detailed data log is given, which contains flight line times and positions, sensor data information, and oil sighting times and locations. The areas in which oil was detected are indicated on the maps of the search zone.

The use of remote sensing during similar oil spill incidents is discussed and recommendations are made which will allow more effective mobilization and use of remotely sensed information. An algorithm is presented which will allow the determination of the time required to search an area which contains an oil spill. Included, are calculations of times that would be required by the three CCRS aircraft types to search the KURDISTAN oil spill area.

Four, Experimental and General Review, Significant.

Laurentian Channel about 50 miles north of Glace Bay, Nova Scotia; March, 1979.

Daedalus type DS-1260 Multispectral Scanner (MSS), RCS - Low Light Level Television Camera, Vinten type 492, 70 mm reconnaissance camera, Multi-detector Electro-optical Imaging Scanner (MEIS).

Remote sensing, Oil pollution, Oil spills, Sensors.

Comments - Nine sorties over the KURDISTAN oil spill area are documented. Flight lines, environmental conditions, etc., as well as the occurances of oil are given. Data Processing and Analysis Techniques are discussed.

Parker, H.D. and D. Cormack, (1979), "Evaluation of Infrared Line Scan (IRLS) and Side-Looking Airborne Radar (SLAR) Over Controlled Oil Spills in the North Atlantic", Int. Symposium on Remote Sensing of Environment, Proc., 15th, Ann Arbor, Michigan, 20 pages. Canada Centre for Remote Sensing, Ottawa, Ontario. CCRS # 1028295.

Summary - A series of experiments are being carried out in the North Sea jointly by Warren Spring Laboratory and the Royal Signals and Radar Establishment to evaluate the use of IRLS (8 - 14 μm) and Q-band, (H) polarised, SLAR for remote sensing of oil on the sea. The preliminary results of this work are reported here and the co-ordination of the experiments and the methods used to gather sea truth data, in particular oil film thickness, are discussed. Imagery resulting from these experiments is presented for two oils, a North Sea crude and a Middle East crude, together with imagery of an accidental spill of heavy fuel oil. These experiments have shown that both sensors will show the presence of oil, but the imagery from the IRLS is more easily interpreted and also provides some information on the quantity of oil on the sea. The SLAR technique shows considerable promise, and a SLAR is likely to be included in a future remote sensing system to extend the capability beyond the weather limitations of IRLS.

Two, Experimental, Highly Significant.
Southern North Sea.
Infrared Line Scan (8 - 14 μm) and Q-band (H) polarised SLAR.
Remote sensing, Oil spills, North Sea, Infrared Line Scan, Infrared, Microwave, SLAR.

Author's Conclusions - 1. Both the SLAR (Q-band), (H) polarised) and the IRLS (8 - 14 μm) were able to detect oil on the sea and, in addition, the IRLS provided information on the structure of the oil slick.

2. IRLS provided high contrast imagery that could easily be interpreted, the SLAR showed lower contrast and so interpretation was more difficult.

3. The threshold thickness for the IRLS was found to be of the order of 10 μm (probably 25 - 50 μm) and for the SLAR of the order of 100 μm.

Note: This very low threshold for SLAR may result in extremely large areas of sea being shown as being contaminated with oil since in the event of a real spill the area of sea covered by sheen is extensive. The area of interest would normally be located at the downwind edge, however.

4. The adoption of a thickness of 1000 μm for areas appearing hotter than the sea, in the IRLS imagery, and 100 μm for those apprently colder, led to an estimate of the quantity of oil (as a water-in-oil emulsion) on the sea surface within an order of magnitude. From these two experiments a mean thickness of 15 - 20 μm over the area detected by radar was found to fit the data but see note above.

5. It may be possible to distinguish broad categories of oil type from the IRLS imagery because of their different behaviour at sea.

Rambie, G.S. Jr., (April 1974), "A Practical Oil Sensor", *Proceedings of the Ninth International Symposium on Remote Sensing of Environment*, Vol. III, pp. 1682-1694. Ramco, Irving, Texas. CCRS # 1005076.

Abstract - A very functional hydrocarbon sensor has been built to detect the incursion of oil on a body of water. The practicality of this sensor has been proven over a three year development and test period.

This two wavelength active monostatic infrared sensor detects the anomalous dispersion that occurs in petroleum products as a result of the carbon-hydrogen stretch bands near 3.4 micrometers. By ratioing the reflected power received at the two wavelengths the quotient is a signature proportional to reflectivity only, being independent of common mode effects such as range and time variable surface roughness caused by waves.

Field tests were successfully conducted on both inland and ocean waters and environmental tests to military specifications MIL-E-16400 and MIL-STD-810B have shown the usefulness of the sensor in a field instrument.

Nil, General Review, Normal.
Remote sensing, Oil sensor, Reflectance.

Author's Conclusions - The practicality of the Oil Sensor has been shown. The basis for its ability to detect oil incursions on water is scientifically sound. It has been carefully engineered using proven electrical and optical components. Extensive tests have shown that it will work reliably in a field environment. It was developed under the direction and advice of people who have a demonstrated need for detecting oil on water. Hardware now exists for application by users.

Rawson, R.F. and C.L. Liskow, (1981), "Radar Reflectivity Measurements of Ocean Surface With and Without a Surface Coat of Oil", In: Geoscience and Remote Sensing Symp. - IGARSS Vol. 2, pp. 1268-1273. Radar and Optics Division, ERIM, Ann Arbor, Michigan. CCRS # 1035111.

Introduction - This paper presents an example of a technique to obtain radar backscatter coefficients for ocean clutter with and without surface crude oil present. The data were derived from a test conducted in the Atlantic Ocean, off the coast of New Jersey in November 1978. The experiment was sponsored by NASA LaRC. The experiment was directed by Dr. W. Croswell, NASA LaRC. The object of the experiment was to release a small amount of crude oil on the ocean surface and detect its presence using a variety of sensors. The sensor data would be used to compute the volume of oil spilled.

The X/L SAR was included to assess its capability of detecting the oil spill for a variety of depression angles, look directions relative to the sea, and transmitted wavelengths.

Nil, Experimental, Significant.

New Jersey Coast; November 1973.

ERIM X/L Radar.

Remote sensing, Oil spill, Radar, Depression angle, Look direction, Backscatter.

Author's Conclusion - The SAR was capable of detecting the oil spill at a depression angle of 54° to 47° (the extent of the slick). The ratio of the backscatter coefficients for ocean and ocean with oil was approximately 3 dB for the example given. Further analysis will be performed to determine how the ratio varies with depression angle.

Rayner, D.M., (October 1980), "Effect of Surface Temperatures on the Remote Sensing of Oil Using Laser Fluorosensors", Environmental Protection Service, Environment Canada, Ottawa, Ontario, 14 pages. (Also available in French.) Division of Biological Science, National Research Council of Canada, Ottawa, Ontario. EPS-4-EC-80-2.

Abstract - The applicability of laser fluorosensors in the detection of oil spills in an Arctic environment and the effect of temperature on the fluorescence properties of oils were studied. Oil fluorescence spectral distribution was not affected by temperature. Light refined petroleum products fluoresced more efficiently at low temperatures, whereas crude oils and heavy refined products showed little change. Laser fluorosensor performance was enhanced by lowering the surface temperature.

Eight, General Review, Significant.

Laser Fluorosensor.

Remote sensing, Oil spills, Laser fluorosensor, Fluorescence, Temperatures.

Author's Conclusions - Surface temperatures ranging between 25 and -40°C affect laser fluorosensor performance in that the ability to detect light, refined petroleum products is enhanced at low temperatures. These products are already the most easily detected oils at 25°C. The fluorescence properties of crude oils and heavy refined products are largely unaffected by temperature in the above range and previous studies of their detectability, carried out at 25°C, are still relevant at -40°C.

Rayner, D.M., (October 1980), "Thin Oil Film Detection Limits of Laser Fluorosensors", Environmental Protection Service, Department of Environment, Ottawa, Ontario, 19 pages. (Also available in French). Division of Biological Sciences, National Research Council, Ottawa, Ontario.

Abstract - Fluorosensor equations were derived for the case of thin translucent oil films. Absorption coefficients were measured for five crude oils as a function of wavelength within the 230 to 400 nm range. Fluorescence efficiencies were also measured over a range of film thicknesses at three excitation wavelengths for these oils. This experimental data allowed verification of the fluorosensor equations and justified certain simplifications. Thin film detection limits were calculated for a sensor with current specifications and means of improving sensor performance were discussed.

Eight, Experimental and General Review, Significant.

Laser Fluorosensor.

Remote sensing, Detection, Oil films, Laser fluorosensor, Fluorescence.

Author's Conclusions - The oil properties on which the thin film detection limit depends are the fluorescence efficiency ($\eta(\lambda)$) and the absorption coefficient (α) at the excitation wavelength. Reabsorption of emitted fluorescence can be neglected due to the nature of the dependence of α on wavelength (i.e. α_{ex} is found to be significantly greater than α over the emission band). Consequently spectral distributions are not affected appreciably by film thickness. Our crude oil samples became translucent at thicknesses under 5 to 20 μm at 337 nm depending on the oil. The current minimum detectable film thickness is about 1 μm for all the oils at 337 nm. Marked improvement in fluorosensor performance can be expected if advantage is taken of the increase in absorption coefficient at lower wavelengths by exciting at such wavelengths. Eximer lasers are available which not only allow this but also offer more power leading to a further improvement in performance.

Rayner, D.M. and A.G. Szabo, (March 1978), "A Laboratory Study of the Potential of Time-Resolved Laser Fluorosensors: Supplement", Sensor Working Group, Canada Centre for Remote Sensing, Ottawa, Ontario, Canada, 46 pages. Division of Biological Sciences, National Research Council of Canada, Ottawa, Ontario.

Introduction - This supplement to 'A Laboratory Study of the Potential of Time-Resolved Laser Fluorosensors' describes the fluorescence properties of an additional twenty-five samples of likely fluorosensor targets. As well as some further examples of the type of oils studied for the main report the new selection contains sampled related to other roles of fluorosensing besides marine oil spill detection. Included are dyes which may be used as tracers in hydrographic studies, samples from mine tailing ponds, oils which may pollute inland waters, a high boiling point aromatic oil used in coal liquifaction, pulp mill effluent and fish oil.

The fluorescence spectra are presented using the same scales and format as in the main report. Thus direct comparison between the spectra in the main report and in the supplement is possible. In the supplement we have omitted the actual decay profiles which are in any case dependent on the lamp profile. Should they be required in future the decay profiles are stored on floppy disk at NRC.

Experimental techniques were exactly the same as those used in the main study part from the additional use of a Perkin-Elmer MFP-44A spectrofluorimeter to obtain the spectra of the low optical density mine tailings using right angle rather than front surface viewing.

Nil, General Review, Normal.

Laser Fluorosensor.

Remote sensing, Petroleum products, Laser fluorosensor, Fluorescence.

Author's Conclusions - All the crude oil and petroleum products examined in this supplementary study show fluorescence properties consistent with the conclusions of the main report.

Of the new classes of targets studied all show some potential for fluorosensing. Pulp mill effluent fluoresces efficiently and should be detected easily. Coal mine tailing pond water also fluoresces, although less strongly than pulp mill effluent, and would be detectable providing the optical depth were great enough. The potential for the sensing of these aqueous targets will be affected significantly by the background fluorescence of the waters in the absence of effluent. We have no information on this topic. A large scale survey of the induced background fluorescence of Canadian waters would be invaluable in the assessment of fluorosensor roles. Although background fluorescence will not add to the signal from optically dense oil slicks it could be important where a spill has spread significantly to allow laser light to penetrate into the water below, and in estimating the contrast to be expected between open water and an oil spill.

Besides reinforcing the conclusions of our main report the preliminary studies in this supplement show that several other roles of fluorosensing appear feasible.

Rayner, D.M., M. Lee and A.G. Szabo, (September 1978), "Effect of sea-state on the performance of laser fluorosensors", Applied Optics, Vol. 17, pp. 2730-2733. National Research Council of Canada.

Abstract - The effect of the sea-state on the performance of laser fluorosensors operating in both spectral and temporal modes is estimated. For the spectral mode, calculations of the dependence of reflective losses on the angle of incidence show that the attenuation of the fluorescence return is not significantly affected for the range of sea-states expected in deep water. In the temporal mode the return signal is distorted by the sea-state. Fortuitously this distortion does not significantly alter the full width at half maximum (FWHM), a parameter from which decay times can be estimated.

Nine, Theoretical, Significant.
Laser Fluorosensor.
Remote sensing, Laser fluorosensor, Sea-state.

Author's Conclusions - In theory the sea-state will effect the performance of laser fluorosensors. However, we have shown that for spectral measurements the effect is negligible for the sea-states to be expected in deep water. For temporal measurements the instrument response is distorted, but if the FWHM technique is used for deconvolution no significant extra error is introduced above those already associated with the technique. More sophisticated deconvolution techniques, capable of greater accuracy when the decay function is known to be single exponential, are thrown badly off by wave action. As there are practical reasons which also make these techniques unsuitable at the present time, the temporal capabilities of current sensors (using the FWHM technique) will not be effected by the sea-state either.

Rayner, D.M. and R. O'Neil*, (1979), "Laser Fluorosensors for Remote Environmental Monitoring", Optics News, Summer, 5 pages. National Research Council, Ottawa, Ontario; Canada Centre for Remote Sensing, Ottawa, Ontario*. CCRS # 1020298.

Introduction (Modified) - Fluorescence spectroscopy is used in a wide range of disciplines as both a qualitative and a quantitative analytical technique. The development of the laser has now allowed this method to be adapted to the remote-sensing role of monitoring environmental parameters from the air. Many environmental pollutants have been shown to have characteristic fluorescence properties lending them to possible detection and identification by a laser fluorosensor.

Oil-spill monitoring has been a primary target of fluorosensor development programs. The remote assessment of chlorophyll concentration as an indicator of water quality is also under study.

Eleven, General Review, Highly Significant.

Remote sensing, Oil spills, Environmental monitoring, Laser fluorosensors, Fluorescence.

Comments - The basic concepts of fluorescence and the laser fluorosensing are discussed. A major effort in laser fluorosensor development has been directed toward applications in the remote detection and characterization of oil spills. Other environmental monitoring roles as well as future laser fluorosensing developments are discussed.

Sandness, G.A. and S.B. Ailes, (1977), "Prototype Active Scanner for Nighttime Oil Spill Mapping and Classification", *Proceedings of the 11th International Symposium on Remote Sensing of Environment*, Ann Arbor, Michigan, pp. 1445-1452. Battelle Pacific Northwest Laboratories, Richland, Washington. CCRS # 1014349.

Abstract - A prototype, active, aerial scanner system has been constructed for nighttime water pollution detection and nighttime multispectral imaging of the ground.

An arc lamp is used to produce the transmitted light and four detector channels provide a multispectral measurement capability. The feasibility of the design concept has been demonstrated by laboratory and flight tests of the prototype system.

Nil, Experimental, Significant.

November 1974 and August 1975.

Active multispectral scanner (Xenon and mercury-xenon arc lamp illumination).

Remote sensing, Oil spills, Active, Multispectral scanner, Classification, Detection.

Comments - The first nighttime flight tests of the prototype system, imaged on a motor oil slick, from an altitude of 300 m and the estimated thickness of the oil was 40 m. In another test, Rhodamine B, a fluorescent tracer dye, was imaged from 300 m at a concentration of less than 1 ppm.

In August 1975, the scanner was used in a theoretical study to examine the behaviour of a thermal plume produced by discharging of cooling water from a nuclear reactor. The scanner was mounted on a crane 7 m above the theoretical test basin, and the imagery obtained graphically and quantitatively displayed the dynamic behaviour of the plume under the influence of waves and currents in the model sea. Rhodamine B concentrations of less than 5 ppb were readily mapped at scan angles up to $\pm 55^\circ$ and slant ranges up to 12 m.

These measurements together with flight test results have shown that an operational oil spill mapping and classification capability will be attainable with the construction of a second generation scanner.

Sato, T., Y. Suzuki, H. Kashiwagi, M. Nanjo* and Y. Kakui*, (January 1978), "A Method for Remote Detection of Oil Spills Using Laser Excited Raman Backscattering and Backscattered Fluorescence", IEEE Journal of Oceanic Engineering, Vol. OE-3, No. 1, 4 pages. Laser Research Section, Electrotechnical Lab., Tokyo, Japan; Osaka Branch, Electrotechnical Lab., Amagasaki, Japan*. CCRS # 1021432.

Abstract - A laser method for the remote detection of oil present as a pollutant in the sea water using Raman backscattering and backscattered fluorescence is discussed. The scattering spectra of oils obtained by using a laser Raman spectrometer that employs a CW Ar laser are described. The backscattering spectra of oils obtained by a laser radar technique in the laboratory and the field are also described. Furthermore, theoretical performance of a laser radar with a CW laser or a pulsed laser for the detection of Raman backscattering of kerosene is discussed.

Nine, Theoretical and Experimental, Significant.
Laser Raman Spectrophotometer.
Remote sensing, Oil spills, Raman spectra, Fluorescence, Laser.

Author's Conclusion - Raman backscattering and backscattered fluorescence of kerosene, light oil, heavy oil, and heavy crude oil have been investigated in the laboratory and in a harbor for the remote detection of oil by using laser radar systems that employ either a CW Ar Laser or the SH of a pulsed Y AG laser. Furthermore, the theoretical performance of the laser radar systems has been discussed by estimating the S/N of the systems for the detection of Raman backscattering of kerosene. We plan to investigate the backscattered fluorescence of oil excited by the fourth harmonic of a pulsed Y AG laser for the remote detection of oils.

Sheives, T.C., J.W. Rouse, Jr. and W.T. Mayo, Jr., (April 1974), "Remote Measurement of Water Pollution with a Lidar Polarimeter", Proceedings of the Ninth International Symposium on Remote Sensing of Environment, Vol. III, pp. 1695-1704. Remote Sensing Center, Texas A&M University, College Station, Texas. CCRS # 1005077.

Abstract - This paper examines a dual polarization laser backscatter system as a method for remote measurements of certain water quality parameters. Analytical models for describing the backscatter from turbid water and oil on turbid water are presented and compared with experimental data. Laser backscatter field measurements from natural waterways are presented and compared with simultaneous ground observations of the water quality parameters: turbidity, suspended solids, and transmittance. The results of this study show that the analytical models appear valid and that the sensor investigated is applicable to remote measurements of these water quality parameters and oil spills on water.

Seven, Theoretical and Experimental, Significant.
Lidar Polarimeter.
Remote sensing, Water pollution, Lidar, Laser radar.

Author's Conclusions (Modified) - The analytical model for describing the backscatter from smooth surfaced, turbid water developed in this investigation included single scatter and multiple scatter effects. A comparison of the experimental data with the analytical model showed that the analytical model was valid and that single scatter effects cannot be ignored, except for scattering from a very dense medium. The experimental laboratory data for backscatter from turbid water also showed that the depolarization ratio: 1) remained constant as a function of particle concentration at a low particle concentration; 2) varied directly with particle concentration at high particle concentrations; and 3) varied directly with the receiver field of view.

Field measurement data from several natural waterways showed that the like and cross polarized returns and the depolarization ratio, varied directly with the water quality parameters turbidity and suspended solids, and inversely with transmittance.

The analytical model developed in this investigation for describing the backscatter from oil on water included the effect on the backscatter of the change in refractive index and attenuation due to the presence of oil on water. Experimental laboratory data with laterally homogeneous oil layers verified the validity of the analytical model and established characteristics of the data: 1) the presence of oil on turbid water does not significantly alter the depolarization ratio; and 2) the attenuation due to oil is a function of oil type, oil thickness, and excitation wavelength. Considering these effects on the backscatter, a detection scheme was presented whereby the presence of oil on water can be established using a single wavelength lidar polarimeter. A detection, type identification, and possible thickness measurement scheme was also presented using a dual wavelength lidar polarimeter. These results strongly support the use of a lidar polarimeter for oil pollution detection and measurement.

Singh, R.P., (December 1982), "Microwave Remote Sensing of Oil Slicks Over the Ocean Surface", Canadian Journal of Remote Sensing, Vol. 8, No. 2, pp. 126-136. University of Alberta. CCRS # 1038334.

Summary - Offshore oil exploration and indiscriminate dumping of various wastes in the ocean seriously affect the reflectivity and emissivity of ocean surface. In this paper we have considered the effect of oil slick thickness over the ocean surface and have studied the response of microwaves in both the polarizations. With the help of a model of varying slick thicknesses backed by ocean surface, we have accounted for multiple reflections during the oil slicks. The reflection coefficients for both polarizations have been computed as functions of oil slick thickness and operating frequencies. It is shown that the brightness temperature increases with increasing thickness of oil slicks. The variation of brightness temperature of slick-covered ocean surface is found to be oscillatory. The frequency variation of brightness temperature is found to increase steadily with increasing oil slick thickness and becomes maximum towards the lower operating frequencies. Detailed calculations using various models are very helpful in interpretation of active and passive microwave remote sensing data of the open and oil slicked ocean surface.

Twenty eight, Experimental, Significant.
Remote sensing, Oil slick, Ocean, Microwave region.

Author's Conclusion - The computed results and foregoing discussion show that the microwave response of quasicalm oil slick-covered ocean surface is highly dependent on the varying oil slick thicknesses, varying dielectric constants of slick forming oil, dielectric constant and

and surface temperature of ocean surface. Detailed computations with realistic modelling and physical parameters are very important for the useful interpretation of remote sensing data using active and passive radiometers. Using this information as reference data, the contribution of rough surface can be deciphered from the measured data and the amplitude and wavelength of capillary waves and oil slick thickness can be determined.

Smith, M.F., (October 1978), "Oil Pollution Detection and Sensing; Volume 2, A Bibliography with Abstracts", National Technical Information Service. CCRS # 1018064.

Abstract - Citations of research on sampling, detection, and chemical analysis of oil in water are presented. Studies on remote sensing principally using radar, ocean wave damping, and infrared detection are included. The classification, pattern recognition, luminescence, gas chromatography, and neutron activation analysis of oils are reported in these abstracts. The majority of these citations concern oil spills, but studies on oil wastes, industrial wastes, bilge water, and sewage are also covered. (This updated bibliography contains 135 abstracts, 33 of which are new entries to the previous edition.)

One hundred and thirty five, Bibliography, Highly Significant.

Steinvall, O., H. Klevebrant, J. Lexander and A. Widen, (October 1981), "Laser Depth Sounding in the Baltic Sea", Applied Optics, Vol. 20, No. 19, pp. 3284-3286. National Defense Research Institute, Linkoping, Sweden. CCRS # 1030075.

Introduction (Modified) - The feasibility of measuring water depths with an airborne pulsed laser was first demonstrated in 1968 by Hickman and Hogg. Since then several systems have been built and tested and the technique should become operational within the next few years.

This letter reports a recent field test in the Baltic Sea. Earlier trials with rather unsophisticated equipment of our own gave depth penetrations of the order of 10 attenuation lengths outside the southeast part of the Swedish coast. However, theoretical estimations based on optical attenuation profiles pointed toward 20-25 attenuation lengths from an altitude of ~200m. As there was a need to demonstrate the capability of the technique with better equipment there was a joint effort between the Swedish Defence Research Institute (FOA), Optech, Inc., and Canada Centre for Remote Sensing (CCRS) concerning a demonstration of the CCRS MK-II lidar in Sweden.

Nine, General Review, Normal.

Baltic Sea.

CCRS MK II Lidar.

Remote sensing, Laser radar, Fluorescence, Depth sounding, Baltic Sea.

Comments - Authors concluded that the airborne laser bathymetry seems to be very useful in the Baltic Sea for depth sounding. Further experiments are intended to continue this program.

Swaby, L.G. and A.F. Forziati, (December 1969), "Remote Sensing of Oil Slicks", Proceedings Joint Conference on Prevention and Control of Oil Spills, New York, NY, pp. 297-308. Division of Water Quality Research, Federal Water Pollution Control Administration.

Abstract - An overview of remote sensing methods is presented and illustrated with data taken at the Santa Barbara oil spill. The conclusion is reached that such methods possess monitoring capability but so far the ability to identify the slick material as oil has not been demonstrated. The advantages and disadvantages of each method are briefly discussed.

Ten, General Review, Normal.
Remote sensing, Oil spills, Active/Passive.

Author's Conclusions - All methods investigated so far have the ability to detect the presence of a surface film. However, the potential for positive identification of the film substance appears to be offered by multispectral methods only. Unfortunately, the methods (U.V. through IR) by which spectral signatures are detectable become inoperable at night and/or in bad weather. On the other hand, microwave methods possessing all weather capability do not allow spectral differentiation. It may be that other recognition techniques are possible but if so they have yet to be worked out.

A more complete picture of remote sensing of oil spills will emerge after active and fluorescence detection methods have been fully investigated. These sensors will most likely have the capability of detecting and monitoring surface films but not of identifying the contents of the films. Nevertheless, we will have a choice of sensors useful under a variety of situations for detecting films with identification reserved for the laboratory.

Taylor, J.I. and R.W. Stingelin, (1969), "Infrared Imaging for Water Resource Studies", Reprinted from Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers, 95 (HYI) : 175-189, in: The Surveillance Science, Remote Sensing of the Environment, pp. 220-227, (1973). CCRS # 1014967, Library of Congress Catalog # 72-7922.

Abstract - Any object with a temperature above zero degrees Kelvin (-459°F) has molecular motion. Because of this motion-rotation, oscillation, vibration-heat radiation is emitted directly. In general, natural objects emit energy over a broad portion of the electromagnetic spectrum. But if the total radiation of any object is graphically plotted by wavelength, a curve develops which usually has a sharp peak at a particular wavelength. This is called the λmax (wavelength at which maximum radiation occurs). From the work of such researchers as Planck, Wien, and others, it is possible to show both experimentally and empirically that the λmax varies with the temperature of the object. The hotter the object, the shorter the wavelength at which λmax radiation occurs. Conversely, as an object cools, its peak radiation shifts to longer wavelengths. At relatively low temperatures the peak of the radiation curve will be in the infrared. For example, the ambient temperature of the atmosphere is about 300°K; the λmax at this temperature is at 9.7μ. This is well within the range of emitted infrared energy. If we stand near a bonfire or step out into the sun on a hot summer day, we have no difficulty sensing "heat" radiation. However, for cooler objects our body sensors prove too insensitive to record their emissions. What is needed is a sensor that will respond to the longer wavelengths. Further, if we know the peak radiation wavelength of an object, we can design the sensor to be most receptive to the narrow band of wavelengths at or near λmax. This would make it possible

to recognize or distinguish the object against considerable other background radiation or "noise".

Eight, General Review, Normal
Infrared, Water Resources

Comments - Covers general topics of Infrared Imagery including its Nature, Geometry, Recent and Future Applications to Water Resources.

Theodorou, Dr. D.G. and J.C. Pickels*, (September 1971), "Salient Sensor Characteristics for LLLTV Systems", 5th Symposium on Photoelectric Image Devices, London, England, 13 pages. Dalmo Victor Company, Belmont, California; USAF, Wright Patterson Air Force Base, Ohio.*

Introduction (Modified) - The technology of Low Light Level Television (LLLTV) sensor devices has rapidly evolved during the past two years and there are now several excellent sensors available for use in LLLTV cameras. Simultaneously, field requirements of such camera systems have become far more sophisticated than the early days when seeing in the dark was all that was required. The basic performance of the TV sensor, its dynamic response, susceptibility to bright lights, size and power requirements are therefore of paramount importance in the design choice of modern LLLTV cameras.

Although a plethora of sensor data is available from manufacturers, the performance of practical systems, in the long run, depends on the particular application one has in mind. In order to eliminate some of this confusion, a program was undertaken, under the auspices of the United States Air Force, to test and evaluate the difference in performance of various cameras, particularly as they relate to real world conditions.

Thirty nine, General Review, Significant.
Low Light Level Television.
Remote sensing, LLLTV.

Comments - The Isocon camera is very heavy, requires a lot of power and has very poor dynamic response at low light levels. At medium to high light intensities,however, the camera is clearly superior to all other systems.

The ISEC camera is now outdated for most applications.

The MCP/V camera serves its function very well as an inexpensive, lightweight camera. Unless basic changes are made in MCP technology it will always have inferior performance at low light levels, to the IIS and ISIV cameras.

The ISIV camera is a good compromise for a passive LLLTV camera and will undoubtedly play a key role in future LLLTV technology.

Thomson, V., R.A. Neville and R.A. O'Neil*, (1979), "High Contrast Imaging of an Oil Slick by means of a Low Light Level Television", Canada Centre for Remote Sensing, 19 pages. Intera Environmental Consultants Ltd., Ottawa, Ontario; CCRS, Ottawa, Ontario*. CCRS # 1028046.

Abstract - Because of the reflectance of oil films is higher in the near ultra-violet and near infra-red, it is possible to enhance the contrast of oil slicks on the water surface by observing them through a Corning Type 7-51 filter which transmits in the 320-420 nm and the 650-850 regions of the spectrum. The radiance arising from volume scattering in the water column can be reduced by viewing the surface at Brewster's angle (an angle of incidence approximately 53° for water) through a horizontal polarizing filter.

A silicon intensified target (SIT) television camera (RCA model TC1030H) was fitted with a 12.5 mm lens to give a 42° x 54° field of view. To enhance the contrast of oil slicks on the water surface the filters described above were used. This configuration then accentuates sky light reflected from the surface films. Other materials, such as dye, dissolved in the water column are not seen by the television camera.

High contrast images have been obtained with such a television system when flown over a natural oil seep in Baffin Bay and test spills in the Atlantic Ocean.

Though this is a relatively inexpensive system, it is believed to be useful both for surveillance and tactical purposes in oil spill countermeasures activities.

Four, Experimental and General Review, Highly Significant.
Baffin Bay and Coast of New Jersey.

Low Light Level Television System.
Remote sensing, Oil spills, Oil pollution, LLLTV.

Author's Discussion (Modified) - In general, the low light level television system, filtered as discussed in section 4, provides high contrast dynamic imagery of oil slicks under various sky conditions. It has proven to be a valuable tactical sensor as it provides the operator with real-time imagery. Using this system, an operator can readily distinguish an oil slick from, for example, a wind slick or any slick not caused by a surface film having optical properties similar to those of an oil film. As discussed in sections 2 and 3 much of the improved contrast, as compared to visual sightings, can be attributed to the polarizing and spectral filters. It is because these filters severely attenuate the radiance from an already dark sea surface that the high sensitivity of the LLLTV system is required.

The LLLTV system has encountered sea surface conditions under which it is unable to provide unambiguous imagery. These include high sea states where foam is indistinguishable from oil. In another case slush and patches of mixtures of water and small bits of ice were not discriminated from oil. To solve these problems one might consider using a polarizer that can be switched quickly between horizontal and vertical polarization modes synchronously with the 30 hz picture repetition rate. This system should display oil as a flashing signal whereas the remainder of the scene, including foam and ice, would remain constant.

Thomson, V., R.A. Neville and R.A. O'Neil*, (August 1980), "A Bibliography on the Remote Sensing of Oil Pollution", EPS, Environment Canada, Ottawa, 92 pages. Intera Environmental Consultants Ltd., Canada Centre for Remote Sensing*. CCRS # 1026045.

Abstract - A bibliography of the literature on the remote sensing of oil spills has been compiled from a wide variety of sources. The references cover not only specific remote sensing techniques, but also fundamental physical characteristics of the targets which are required for interpretation of the data.

Three hundred and forty nine, General Review, Highly Significant.

Remote Sensing, Oil pollution, Oil spill, Bibliography.

Comments - Bibliography is subdivided into 27 categories for easy reference. Topics include all aspects of remote sensing and oil pollution (or spills). This bibliography was compiled during the initial phases of the remote sensing component of the Arctic Marine Oil Spill Program (AMOP).

Thomson, V., R.A. Neville and R.A. O'Neil[*], (1980), "A Bibliography on the Topic of Remote Sensing of Oil Pollution", Canada Centre for Remote Sensing, Ottawa, Ontario, 93 pages. Intera Environmental Consultants Ltd., Ottawa; CCRS, Ottawa[*]; CCRS # 1024272.

Abstract - A bibliography of the literature on the remote sensing of oil spills has been compiled from a wide variety of sources. The references cover not only specific remote sensing techniques, but also the fundamental physical characteristics of the targets which are required for the interpretation of the data.

Three hundred and forty nine, General Review, Highly Significant.

Remote Sensing, Oil pollution, Oil spill, Bibliography.

Comments - Bibliography is subdivided into categories for easy reference. Topics include all aspects of remote sensing and oil pollution (or spills). This bibliography was compiled during the initial phases of the remote sensing component of the Arctic Marine Oil Spill Program (AMOP).

Troy, B.E., and J.P. Hollinger, (May 1977), "The Measurement of Oil Spill Volume by a Passive Microwave Imager", U.S. Coast Guard, Washington, D.C. 67 pages. Naval Research Lab., Washington, D.C. CCRS # 1011923; NRL Memorandum Report 3515.

Abstract - An airborne passive microwave system has been developed and used in a test program to detect a marine oil spill and to determine its thickness and volume. A controlled spill of 2040 liters (533 gallons) of No. 2 fuel oil was conducted from a Coast Guard vessel 20 miles off the Virginia shore. Microwave images of the spill were obtained at both 22.4 and 31.0 GHz on five consecutive aircraft passes over the visible oil slick. Wind and weather conditions were moderate during the test.

The microwave images were processed on a computer and shown on a color television display system. These color images revealed a small region of relatively thick oil, surrounded by a larger region of much thinner oil, in agreement with results from an earlier program. The thin oil region corresponded to the visible oil slick and showed up clearly in the color images against the unpolluted open sea. It is thus possible to outline the entire visible slick and to locate the thick oil regions within it by means of a microwave image. Maximum oil thickness was approximately 0.6 mm in the thick region which was located on the downwind side of the visible slick. The oil spill volume was determined by integrating the oil thickness over area in the computer.

Each microwave image of the spill was made in the few seconds necessary for the aircraft to pass over the spill. This rapid data-taking capability is a significant improvement over the earlier developmental program which used fixed downward-looking radiometers, and required approximately one hour and a dozen aircraft passes to gather the data necessary to

reconstruct a microwave picture of the slick. Therefore, the development of the imager and the progress in analysis of the imager data represent a large step toward an airborne system for making real-time determination of oil spill volume.

Twenty two, Experimental and General Review, Highly Significant.
20 miles off the Virginia coast; 1975.
Passive Microwave Imager.
Water pollution, Oil pollution, Oil slick thickness, Oil slick volume, Oil slick spreading, Oil slick detection, Remote sensing, Passive microwave radiometry, Microwave imagery.

Author's Summary (Modified) - The NRL microwave imager has been used to detect an oil slick on the surface of the ocean, and to make microwave brightness temperature images of the slick. The use of microwave imagery on this flight represents a great advance over the use of fixed radiometers in the earlier flights. The imager represents a large step towards a quick-response, real-time oil spill detection system.

Computer software has been developed which converts the temperature images to thickness images, and integrates the thickness to obtain volume. The dual frequency capability of the imager is used to avoid ambiguity in the oil thickness measurement, and to eliminate noise in the ocean background which makes spurious contribution to the detection of oil volume.

U.S. Coast Guard, (1978), "AOSS II Ocean Surveillance", U.S. Coast Guard, Washington, D.C., 4 pages. CCRS # 1018927.

Introduction - AOSS II is a multimission airborne ocean surveillance system developed by the U.S. Coast Guard to increase the productivity of its limited aircraft, manpower and capital funds, while meeting increasing mission demands such as enforcement of laws and treaties (ELT) associated with the expanded U.S. Fishery Conservation Zone, the Search and Rescue (SAR) function, urgent marine environmental protection (MEP) response such as the recent Argo Merchant Case, and growing ice reconnaissance misssons.

Nil, General Review, Normal.

SLAR, UV/IR Line Scanner, Passive Microwave Imager, Aerial Camera.

Oil pollution, Surveillance, United States.

Comments - A good, short, general overview of the U.S. Coast Guard AOSS II system.

van der Piepen, H., V. Amann, R. Statter and M. Schroader, (July 1979), "Remote Sensing of Ocean Waters", Laser 79 Opto-Electronics, Munich, Germany, pp. 508-513. Institut fur Optoelekronik, Oberpfaffenhofen, BDR.

Abstract - As a result of the growing demand of the oceanographic community for improved ocean monitoring, new remote sensing concepts and instruments have been applied to the marine environment. The currently used active and passive techniques, their relation to major satellite projects and their application towards the measurement of the most important water parameters are briefly outlined and discussed.

Six, General Review, Normal.

Remote sensing, Oceans, Electromagnetic spectrum, Electromagnetic bands.

Comments - A variety of instruments have been optimized for various oceanic applications and have been used extensively on both aircraft and spacecraft. The intention of this paper was to outline, briefly the various user requirements, remote sensing systems presently investigated, their incorporation into major satellite projects and their application towards the measurement of water parameters. The emphasis was placed on optical and multispectral techniques.

van Kuilenburg, J., P.W.H. Blansjaar, P.J.F. Geerders, K. Kubik, J. van Kuilenburg and A. Rosema, (June 1972), "The Application of Remote Sensing Techniques", Netherlands Interdepartmental Working Community for the Application and Research of Remote Sensing Techniques (NIWARS), Delft, The Netherlands.

Introduction (Modified) - All activities collecting the bulk of information from a distance can be classified as "remote sensing". These activities vary greatly but can generally be said to be concerned with thematic mapping, using visible light, infrared radiation, microwaves and sound waves.

When considering the successful use of remote sensing it should be emphasized that instrumentation is only a fraction of the effort required to realize a useful remote sensing application. To achieve results one must have available the instrumentation, proper groundtruth, a processing system and interpretation capability of the results.

The following is a discussion of the principles of remote sensing and some of the more common remote sensors.

Nil, General Review, Normal.

Photography, MSS, Optical systems, Line scanner, Passive and active microwave systems.

Remote sensing, Sensors, Radiation.

Comments - The general principles of measurement in remote sensing as well as selected sensors operating in various portions of the electromagnetic spectrum are discussed.

Van Kuilenburg, J., (July 1975), "Remote Sensing of Oil Pollution at the Sea Surface I, Review of Remote Sensing Methods Emphasizing Radar", Netherlands Interdepartmental Working Community for the Applications of Remote Sensing Techniques (NIWARS), Delft, The Netherlands. 28 pages. NTIS N77-23582.

Summary - The problem of monitoring oil pollution is stated and the remote sensing methods applicable for that purpose are reviewed. A more detailed discussion is presented on radar observations of oil slicks and of the surrounding sea surface. A selected bibliography is presented.

Forty five, General Review, Normal.
Remote sensing, Oil spills, Oil pollution, Radar.

Comments - This general report reviews remote sensing methods as they apply to the detection and monitoring of oil pollution, with a focus on microwave techniques.

Vass, P.A. and J.L. van Genderen, (April 1978), "Monitoring Environmental Pollution by Remote Sensing", International Symposium on Remote Sensing of Environment, Proceedings Manila, Philippines, Vol. 1, pp. 219-234. Fairey Survey Limited, Berkshire, England. CCRS # 1017420.

Abstract - During the past twenty years, the polluted environment has become one of the major concerns of industrial societies. Continued growth in industrial development and in the wastes from an ever increasing number of sources, together with the need to preserve nature in its many forms have found attention focused on the burgeoning problems of environmental pollution and the demand for the early and reliable detection of vegetation stress caused by pollution, so that effective monitoring and control measures can be introduced. The paper outlines the various types of environmental pollution which may be studied by remote sensing. Also man's detrimental effect on the land as a result of his development activities is discussed; this is of particular relevance to developing countries. The role of different remote sensors such as airborne cameras (including panchromatic, colour, colour infrared and multiband systems), airborne thermal and multispectral line scanners, side looking radar and satellite imagery for the identification and monitoring of the environmental pollutants and their effect will be evaluated.

Thirty six, General Review, Normal.

Airborne cameras, Thermal and multispectral line scanners, Side looking radar.

Remote sensing, Sensors, Monitoring, Pollution.

Comments - Environmental studies now play a major role in all phases of construction planning and operation. Data collection is necessary to establish baseline environmental conditions, as well as to determine the extent of impacts of existing facilities. These require massive field investigation programs. This report discusses the role of remote sensing technology to provide an efficient and systematic approach to environmental data collection and field survey planning.

Waksberg, A., S. Sizgoric and D. Bennett, (December 1971),
"Study of a CO_2 Laser Radar Imaging System", *Aerospace Electronics Symposium*, Toronto, Ontario, pp. 423-424.
RCA Limited.

Abstract - This is a brief description of our study into the possible use of airborne CO_2 laser "side looking radar" at 10.6 u for earth mapping research. More detailed analysis can be found elsewhere.

Five, General Review, Normal.

CO_2 Laser Radar System.

Remote sensing, Laser, Radar.

Comments - Basic operational concepts are described and possible applications of the CO_2 Laser Radar System are discussed.

Watson, R.D., W.R. Hemphill and R.C. Bigelow, (1975),
"Remote Sensing of Luminescing Environmental Pollutants
Using a Fraunhofer Line Discriminator (FLD)", U.S. Geological
Survey, Denver, Colorado.

Abstract - A redesigned Fraunhofer Line Discriminator (FLD) tested in both ground-based and airborne experiments for 18 months (1974-75) to determine its ability to detect luminescing pollutants, has demonstrated the capability of operating at selected Fraunhofer wavelengths throughout the visible spectrum, with a sensitivity sufficient to detect 0.25 parts per billion rhodamine WT dye in 0.5 m depth of water at 20° C. The instrument has been used to detect and monitor several sources of pollution including oil spills and seeps, sewage effluent, phosphate processing effluent, and paper mill effluent. Selected luminescent dyes that could be used as tracers in pollutant transport studies were monitored in real time from helicopter platform. A comparison of laboratory measurements used to predict the detectivity of a given pollutant and actual field measurements with the FLD demonstrates that the laboratory technique can be used reliably to predict the detectivity of these materials in the field with the FLD.

Fifteen, Experimental and General Review.

Santa Barbara Channel, California; Denver, Colorado; Perry, Florida and Central Florida; 1974-1975.

Fraunhofer Line Discriminator (FLD).

Remote sensing, Environmental pollutants, Fraunhofer line discriminator, Fluorescence.

Author's Summary - In summary, ground-based and airborne experiments made during 1974 and 1975 with a redesigned Fraunhofer Line Discriminator to test its ability to detect

luminescing pollutants yield these results:

1. The improved Fraunhofer Line Discriminator (FLD) has demonstrated the capability of operating at selected Fraunhofer wavelengths throughout the visible spectrum, with a sensitivity sufficient to detect 0.25 ppb rhodamine WT dye in 0.5 m depth of water.

2. Laboratory techniques developed and refined to permit the quantification of luminescing pollutants in terms of rhodamine WT equivalency reliably predict the detectivity of these materials in the field with an improved FLD.

3. Luminescent dyes can be used as a tracer in the study of transport of pollutants, since they can be monitored in real time using an airborne FLD without interference with normal dispersion of the dye cloud.

4. Helicopter tests over areas of known pollution, such as oil spills and seeps, sewage effluent, and selected industrial wastes indicate that the FLD can serve as an effective remote-sensing tool to distinguish and monitor as a function of time pollutants that exhibit natural luminescence.

5. At low concentrations of a pollutant, where a sensitive technique is required for detection from a remote-sensing platform, the FLD demonstrates a linear response to varying concentration, and with appropriate laboratory calibration, provides the means to quantitatively map the distribution of luminescent pollutants.

Watson, R.D., M.E. Henry, A.F. Theisen, T.J. Donovan and W.R. Hemphill*, (1978), "Marine Monitoring of Natural Oil Slicks and Man Made Wastes Utilizing an Airborne Imaging Fraunhofer Line Discriminator", Reference Incomplete, pp. 667-671. U.S. Geological Survey, Flagstaff, Arizona; U.S. Geological Survey, Reston, Virginia*. CCRS # 1007853.

Abstract - Accurate measurements of the areal extent of oil slicks from selected seeps in Santa Barbara Channel, California, have been achieved using a Fraunhofer Line Discriminator (FLD) operating in an imaging mode. The distribution of the oil slick as indicated on FLD images correlated well with aerial photographs, visual observation, surface verification, and simultaneous television monitoring. The advantages of this measurement technique in pollution monitoring include high sensitivity and real-time display of luminescence grey-level maps that include up to 94 grey levels. No change in luminescence with oil film thickness occurs for the Santa Barbara measurements due to the high specific gravity of this oil. Laboratory measurements on a suite of oil samples with specific gravities varying from 0.73 to 0.96 indicates positive correlation between oil film thickness and luminescence for oils of specific gravity of less than 0.875.

Measurements on additional pollutants, including lignin sulfonate, Foley, Florida; phosphate processing effluents, Lakeland, Florida; oil refinery waste, Casper, Wyoming; sewage effluents at seven locations in the Denver, Colorado area; feed lot effluent east of Denver; sludge (wet, dry and ploughed) at the Denver sewage plant; and algae blooms, Ashurst Lake, Arizona: demonstrate the feasibility of using the Fraunhofer Line Discriminator in many pollution monitoring applications. Visual inspection, color aerial photography, FLD measurement of reflectance, and bore-sighted

video monitor images were used to assess the correlation of areal extent of the pollutant with the luminescence measurements.

Nineteen, General Review, Normal.

Fraunhofer Line Discriminator.

Remote sensing, Oil spills, Monitoring, Detection, Fraunhofer line discriminator, Fluorescence.

Author's Conclusions - The FLD imaging system can be used to accurately map the areal extent and surface pattern of oil from natural seeps. The mapping method is sensitive, rapid, and of relatively low cost and therefore is useful in assessment of oil pollution. FLD imaging techniques can be extended to other types of pollution and when the measurements are free from interference, results can potentially be quantified in terms of pollution concentration.

Webb, W.A. and H.G. Eldering, (May 1975), "Optimization and Evaluation of a Fluorescence Oil Spill Detector, Volume I - Laboratory Measurements and Field Evaluation", Dept. of Transportation, U.S. Coast Guard, Washington, D.C., 108 pages. Baird-Atomic Inc., Bedford, Mass. CCRS # 1018697.

Abstract - The work described in this report was directed at maximizing the detection range of an automatic fluorescence oil spill detector and evaluating the detection capabilities of this detector against a wide range of petroleum oils. On the basis of this evaluation, a Scanning Oil Spill detector was designed; this design is presented in Volume II of this report, subtitled Prototype Design.

Corrected fluorescence spectra of 22 petroleum oils at several film thicknesses are presented, and fluorescence spectral distribution and intensity of these oils are compared. A detection algorithm which discriminates oil from marine fluorescence on the basis of fluorescence measurements in two spectral regions is described. This detection algorithm was evaluated in a 6-week program of continuous automatic harbor monitoring.

Laboratory and field tests demonstrated that oil fluorescence may be automatically and consistently discriminated from marine fluorescence. Maximum night detection range is a function of instrument operations conditions. When the flash lamp is operated at maximum brightness, estimated night detection range of this detector is greater than 350 meters for most oils at film thicknesses down to at least 10 microns. When the flash lamp is operated under conditions that result in a lamp life of 10^7 - 10^8 flashes, detection range is greater than 200 meters.

Three, Experimental, Significant.

Scanning oil spill detector.

Remote sensing, Oil spills, Detection, Ultraviolet, Fluorescence, Monitoring.

Author's Conclusions (Modified) - In the course of this optimization and evaluation of the MAPS fluorescence oil spill monitor, the following conclusions have been reached;

1) By measuring fluorescence intensity in the regions, 320-400 nm and 440-650 nm, the large majority of petroleum oils can be remotely discriminated against a background of marine fluorescence.

2) Estimated night detection range is a function of lamp intensity, instrumental optical characteristics, and scene noise.

3) False alarm rate proposed sensor incorporates a backscatter monitor to prevent false alarms caused by heavy fog.

4) Automatic passive detection of oil films by spectral analysis of sky light reflected from film is possible for some backgrounds.

5) Fluorescence signature varies nominally with aging of oil.

6) MAPS demonstrated a sustained capability for remote oil detection in a commercial harbour environment.

White, L.P., (1972), "Air Survey Methods for Water Monitoring", Reprint from Water Pollution Manual, 6 pages. Hunting Surveys and Consultants Ltd. CCRS # 1004373.

Abstract - Airborne remote sensing methods are being used increasingly in a variety of environmental applications of which pollution detection and monitoring is but one. The essential advantages of these methods, which include photographic and non-photographic techniques, are as follows:-

Large areas can be surveyed in a very short time providing 'snapshot' or synoptic views. This is important in areas of rapid change such as tidal estuaries.

Areas can be surveyed without regard to water or ground surface conditions, traffic or other obstacles.

There are no difficulties of access apart from certain flying restrictions.

Airborne detection instruments at present available for water pollution monitoring form only a part of a great variety of instrumentation developed for natural resources surveys. Many of these instruments are adapted from the military and space application versions. The uses of these new systems in the field of environmental control are extensive, provided their advantages and disadvantages are understood.

Nil, General Review, Normal.
Photography, Line Scan, Imaging Radar
Remote sensing, Sensors, Oil spill, Water monitoring.

Comments - Active and passive imaging and non-imaging sensor systems are discussed and more fully explained are photography, linescanners and imaging radar systems. Infrared linescanners offer information concerning the temperature contrasts between water and effluent. Photography, under good weather, and daylight conditions, offers a high resolution image but operational limitations precludes its use as a prime sensor.

White, G.P. and A.V. Arecchi*, (March 1975), "Local Area Pollution Surveillance Systems; A Summary of the Coast Guard's Research and Development Activities", *Conference on Prevention and Control of Oil Pollution*, pp. 123-127. U.S. Coast Guard Headquarters, Washington, D*C.; U.S. Coast Guard R&D Center, Groton, Connecticut.

Abstract - Each year a large number of discharges of oil and other hazardous polluting substances from transportation related processes occur in the navigable waters of the United States. In order to minimize environmental damage from such discharges and to effect prompt containment and cleanup efforts, these spills must be detected and reported as quickly as possible. The Coast Guard has been investigating oil detection techniques and sensor equipment with a view to establishing local area pollution surveillance systems in various port and estuarine areas. The exact configuration of the surveillance systems will be dictated to a large extent by the capabilities of the detectors available. Consequently, the Coast Guard effort, to date, has been concentrated primarily on the development and evaluation of the sensors themselves. This paper summarizes that effort and presents an overview of the work still to be accomplished.

Six, Experimental, Highly Significant.

Remote sensing, In-situ sensors, Surveillance, U.S.C.G, Oil pollution

Comments - A number of remote and in-situ sensors are discussed. Outlined are the sensors, modes of operation, limitations and their various stages of development.

White, J.R. and R.E. Schmidt, (July 1980), "Airborne Surveillance for Ocean Oil Pollution and Prevention", Marine ecology protection, Program arranged by The Oil Conference Committee, pp. 15-20. U.S. Coast Guard.

Introduction (Modified) - Early research in the infrared, ultraviolet, visible, and microwave areas of the electromagnetic spectrum demonstrated that the detection, identification and quantification of oil spills was feasible with remote sensing techniques but that a multi-sensor system would be required to achieve all-weather and lighting conditions performance (White and Breslau, 1978). These initial investigations led to the development of the Airborne Oil Surveillance System, (Edgerton, et al. 1975) and its subsequent modification and installation in a Coast Guard HC-130B aircraft (Meeks, et al. 1977). This experimental system demonstrated that a multi-sensor airborne system could reliably detect and map oil spills in most weather and lighting conditions.

Because of the success of the experimental system, the Coast Guard decided to develop an operational Remote Sensing System for installation on its new medium range aircraft. Current plans are to acquire six AIREYE sensing systems, which will have the capability to detect and map oil spills, and to identify illegally discharging vessels.

This paper reviews the proposed Aireye surveillance system and describes the sensor packages that will be incorporated.

Three, General Review, Significant.

SLAR, IR/UV Line Scanner, An Aerial Reconnaissance Camera, An Airborne Data Annotation System, Active Gated TV, and Control Display and Record Console.

Remote sensing, Aireye, U.S. Coast Guard, Sensor systems.

Comments - The sensor systems to be used in conjunction with the Aireye surveillance system are outlined and their operating parameters are discussed.

White, J.R., R.E. Schmidt and W.E. Plage, (June 1979), "The Aireye Remote Sensing System for Oil Spill Surveillance", Proceedings of the 1979 Oil Spill Conference, Los Angeles, California, pp. 301-304. U.S. Coast Guard, Washington, D.C.

Abstract - The U.S. Coast Guard is developing an airborne, real-time, all-weather, day/night remote-sensing system that will detect oil pollutants and identify violating vessels. The system, designated "Aireye", will be installed on six of the 41 new Falcon 20G jet aircraft, (military designation HU-25A) purchased by the Coast Guard to replace the aging HU-16E Grumman Albatross as its medium-range surveillance aircraft. The sensor system will include a side looking airborne radar, two-channel infrared/ultraviolet line scanner, aerial reconnaissance camera, airborne data annotation system, and a control, display and record console. To identify polluting vessels at night, an active gated television (AGTV) also is being developed for inclusion in the Aireye system. The AGTV will use a one-watt, pulsed, lead vapor laser illuminator and will be capable of recording vessel names at night from a slant range of 700 meters. In addition to an active and passive mode, the AGTV will be capable of both computer and manual target acquisition and tracking. Each of the sensors will produce annotated, hard copy imagery suitable for prosecution of polluting vessels.

Four, General Review, Significant.

Side Looking Airborne Radar, Two-Channel IR/UV Line Scanner, Aerial Reconnaissance Camera, Airborne Data Annotation System, Control Display and Record Console and an Active Gated T.V.

Oil spills, Remote sensing, Surveillance, United States, Remote sensors.

Author's Summary - Aireye will provide the Coast Guard with an effective, operational oil surveillance system. Its sensor capabilities have been proven in prior airborne remote-sensing systems and data obtained by these sensors already have been employed in informal hearings. Remote sensing is no longer a tool of the future. It is becoming a reliable and accepted part of Coast Guard surveillance programs and is expected to help the service conduct its expanding law enforcement missions while reducing overall cost to the taxpayer. The day has arrived when one cannot reasonably be certain he will not be observed violating U.S. pollution laws, even on the darkest night or in the thickest fog bank.

Worsfold, R.D., J.A. Allen and B.E. Fretts, (1975), "The Use of Television for Remote Sensing", Remote Sensing of Environment 4, pp. 5-35. Canada Centre for Remote Sensing. CCRS # 1001861.

Abstract - The Canada Centre for Remote Sensing has been using television since 1971 for their remote sensing programme. It was initially used as a navigation aid, but it was quickly realized that television had other uses in the programme. By adding a video tape recorder to the television camera, a system was put together that could be used to video record the actual path of the aircraft over the terrain and retain the video for comparison with the flight line map and comparison with other data recorded on the same flight. By installing television monitors at the sensor operator positions, the television system could be used for the training of the operators in the use of infrared scanners. With the installation of nonimaging sensor systems that are flown under nonphotographic conditions, it has become evident that television provides a suitable sensor system for comparing the nonimaging system data with the data that has been obtained simultaneously with the television system. The use of television as a sensor was extended when it was recognized that the spectral sensitivity of television in the blue and green spectral regions made it extremely useful for oil spill studies. The test programmes that were carried out at the Canada Centre for Remote Sensing have clearly indicated that television is a very useful sensor system for navigation, flight path recovery for post-flight comparison, and training, and that it should be an integral part for oil spill monitoring.

Twenty one, Experimental and General Review, Significant.

Various Canadian Locations; November 1972, February 1973, April 1974.

Close Circuit Television, Low Light Level Television.

Remote sensing, Oil pollution, Oil spills, Close Circuit Television, Low Light Level Television.

Comments - Test results indicated the usefulness of television for the monitoring of oil spills. The test programme at CCRS was discussed and it was concluded that television has its place as a navigation tool, a sensor operator aid, and a track recovery system for situations of imaging or non-imaging sensor equipment.

Worsfold, R.D. and T.H. Perrott, (1983), "Marine Applications of Satellite Remote Sensing", Presentation Made to the Program Development Workshop on Feasibility of Designating Ocean Dumpsites in the Canadian Beaufort Sea", 14 pages. Remotec Applications Inc.

Introduction (Modified) - The purpose of this paper is to provide a technical description of available satellite remote sensing systems in relation to ocean dump sites. The potential use of satellite data in marine environmental studies, limitations of the systems and data, and means of accessing and interpreting the available information are discussed in terms of the Canadian Beaufort Sea. Recommendations concerning ocean dump sites are made.

Nil, General Review, Normal.
Satellite systems.

Comments - This paper gives a good, short concise general review of satellite data presently available with relevance to certain marine applications including; suspended sediment concentrations, chlorophyll measurements and pollution.

Wright, D.B. and J.A. Wright, (November 1973), "Evaluation of an Infrared Oil Film Monitor", Dept. of Transportation, U.S. Coast Guard, Washington, D.C., 88 pages. Wright & Wright Environmental Engineering, Newton Centre, Mass. CG-D-51-74.

Abstract - An evaluation program was undertaken on a remote oil film detection instrument which utilizes the infrared reflectance spectrum of water surfaces at the 3 micron region. The primary wavelengths measured were 3.1 and 2.7 microns, and hydrocarbon detection was based on a change in the 3.1/2.7 micron signal strength ratio.

The evaluation program consisted of laboratory and in-situ phases. The laboratory phase showed that the instrument could reliably detect hydrocarbon films on a water surface while ignoring non-hydrocarbon films and other pollutants. The instrument would not operate reliably at a height greater than six feet above the water surface; however, a feasibility study determined that a maximum operating height of at least 30 feet could be obtained with some simple design changes in wavelength and optical aperture. The results of the in-situ phase in a congested commercial harbor generally verified the laboratory phase findings and established the instrument's ability to operate effectively in the marine environment.

Nil, General Review, Highly Significant.

Infrared Oil Film Monitor.

Infrared reflectance, Oil film detection, Infrared oil film monitor, Oil pollution monitoring, Remote sensing.

Author's Conclusions - The Infrared Oil Film Monitor can be used to detect hydrocarbon films in a commercial harbor under a wide variety of environmental conditions, when mounted six feet above the water surface. The instrument responds unequivocally to hydrocarbon films and does not respond to non-hydrocarbons. Employing the two primary wavelength channels, the instrument provides an estimate of the thickness of the hydrocarbon film; but it does not provide adequate information to classify the hydrocarbon type. The evaluation program has shown that the two secondary wavelength channels do not operate properly in the existing design. A feasibility study has determined that the instrument's operating height can be increased to over 30 feet and its performance can be optimized by modifying its present design.

Wright, J., (1977), "Current Applications of Remote Oil Monitoring Equipment", Proceedings of the 1977 Oil Spill Conference (Prevention, Behaviour, Control, Cleanup), pp. 209-210. Wright & Wright, Inc., Newton, Massachusetts.

Abstract - Industrial field experience has shown that remote single-point monitoring of the surface of wastewater streams using an infrared reflectance instrument is an effective method of detecting oil films associated with oil in water concentrations as low as one part per million (ppm) in turbulent flow patterns. Four operational case histories of installations in petroleum refineries and manufacturing plants illustrate the application of an infrared oil film.

Five, General Review, Significant.

Electro-optical monitor.

Remote sensing, Monitoring, Detection, Oil and commercial application.

Comments - A number of major petroleum refineries and manufacturing plants have installed an electro-optical monitor which permits automatic, continuous, remote oil spill detection without water contact or sampling by sensing only a single point on the surface of a moving stream. Specific commercial applications of this infrared monitor are discussed and the testing results reviewed.

Wright, J., (1977), "Current Applications of Remote Oil Monitoring Equipment", Proceedings of the 1977 Oil Spill Conference (Prevention, Behaviour, Control, Cleanup), pp. 209-210. Wright & Wright, Inc., Newton, Massachusetts.

Abstract - Industrial field experience has shown that remote single-point monitoring of the surface of wastewater streams using an infrared reflectance instrument is an effective method of detecting oil films associated with oil in water concentrations as low as one part per million (ppm) in turbulent flow patterns. Four operational case histories of installations in petroleum refineries and manufacturing plants illustrate the application of an infrared oil film

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Five, General Review, Significant.

Electro-optical monitor.

Remote sensing, Monitoring, Detection, Oil and Commercial application.

Author's Summary - Industrial field experience now shows that remote, single-point monitoring of wastewater stream surfaces using infrared reflectance instruments is an effective method of detecting and continuously recording oil films associated with concentrations of oil within the entire water column as low as 1 ppm.

Zwick, H.H., R.A. Neville and R.A. O'Neil, (May 1981), "A Recommended Sensor Package for the Detection and Tracking of Oil Spills", Proceedings of an EARSeL-ESA Symposium, Voss, Norway, pp. 77-88. Canada Centre for Remote Sensing. CCRS # 1030101.

Abstract - The Canada Centre for Remote Sensing has undertaken a programme to develop oil detection sensors and to specify a system capable of detecting and tracking oil under a wide variety of environmental conditions. The success of remote sensing of oil varies with the severity of these conditions. Oil on open water under clear skies is a relatively easy target; oil under ice presents a formidable task. Several remote sensing experiments have been carried out to acquire data required for the system specification. Much analysis has been completed, and although the need for more research is indicated, it is possible to recommend the most effective system for the wide variety of conditions experienced in Canada. The recommended sensor complement consists of the laser fluorosensor, an ultraviolet/infrared line scanner (UV/IRLS), a side looking airborne radar (SLAR), a low light level television (LLLTV) and photographic cameras. These sensors must be supported by a real time data annotation, display and analysis system.

Twelve, Experimental and General Review, Highly Significant.

CCRS - Ryan Ku-Band microwave scatterometer, CCRS - ERIM X and L band synthetic aperture radar (SAR).

Oil detection, Remote sensing, Sensor systems, Fluoroscence characteristics, Reflectance characteristics, Thermal characteristics, Raman suppression, capillary wave suppression.

Comments - The presence of oil on the water's surface causes a number of effects which can be detected by various methods using different types of sensors, each optimizes detection of a specific effect or condition.

These effects and corresponding methods and sensors investigated by CCRS are analyzed and discussed. A recommended sensor package comprised of presently operational sensors is given.

APPENDIX C

GLOSSARY

This glossary includes terms, abbreviations, etc., that are commonly employed in Remote Sensing and have relevance to the material presented in this report. A more extensive glossary is provided in the Manual of Remote Sensing, published by the American Society of Photogrammetry in 1983.

GLOSSARY

Absorption:	The process by which radiant energy is absorbed and converted into other forms of energy.
Absorption Band:	A range of wavelengths (or frequencies) in the electromagnetic spectrum within which radiant energy is absorbed by a substance.
Active System:	A remote sensing system that transmits its own electromagnetic emanations at an object(s) and then records the energy reflected or refracted back to the sensor.
Analog:	A form of data display in which values are shown in graphic form, such as curves. Also a form of computing in which values are represented by directly measurable quantities, such as voltages or resistances. Analog computing methods contrast with digital methods in which values are treated numerically.
Angle of Depression:	In SLAR usage, the angle between the horizontal plane passing through the antenna and the line connecting the antenna and the target.
Angle of Incidence:	(1) The angle between the direction of incoming EMR and the normal to the intercepted surface. (2) In SLAR systems this is the angle between the vertical and a line connecting antenna and target.
Angle of Reflection:	The angle that EMR reflected from a surface meets with the perpendicular (normal) to the surface.
Atmospheric Windows:	Those wavelength ranges in which radiation can pass through the atmosphere with relatively little attenuation, in the optical portion of the spectrum, approximately 0.3-2.5, 3.0-4.0, 4.2-5.0 and 7.0-15.0 um.

Attenuation:	In physics, any process in which the flux density (or power, amplitude, intensity, illuminance) of a "parallel beam" of energy decreases with increasing distance from the energy source.
Background Noise:	(1) In recording and reproducing the total system noise independent of whether or not a signal is present. The signal is not to be included as part of the noise. (2) In receiving, the noise in absence of signal modulation on the carrier. Ambient noise detected, measured, or recorded with the signal becomes part of the background noise.
Backscatter:	The scattering of radiant energy into a hemisphere of space bounded by a plane normal to the direction of the incident radiation and lying on the same side as the incident ray; the opposite of forward scatter. Also called backscattering.
Bandwidth:	(1) In an antenna, the range of frequencies within which its performance, with respect to some characteristic, conforms to a specified standard. (2) In a wave, the least frequency interval outside which the power spectrum of time-varying quantity is everywhere less than some specified fraction of its value at a reference frequency. (3) The number of cycles per second between the limits of frequency band.
Beam:	A focused pulse of energy.
Beamwidth:	In SLAR usage this is the angle subtended in the horizontal plane by the radar beam.
Blackbody (symbol bb used as subscript):	An ideal emitter which radiates energy at the maximum possible rate per unit area at each wavelength for any given temperature. A blackbody also absorbs all the radiant energy incident upon it. No actual substance behaves as a true blackbody.

Blackbody Radiation:	The electromagnetic energy radiation emitted by an ideal blackbody.
Cathode Ray Tube (CRT):	A vacuum tube capable of producing a black-and-white or colour image by beaming electrons onto a sensitized screen. As a component of a data processing system, the CRT can be used to provide rapid, pictorial access to numerical data.
Chop:	To interrupt the incoming EMR to a radiometric or similar device, so the detector alternately receives the incoming EMR and EMR from a reference body.
Chopper:	A device, usually one that rotates, used to interrupt a continuous wave signal in a transmitter, receiver, or sensor.
Detection:	A unit is said to be "detected" if the decision rule is able to assign it as belonging only to some given subset of categories from the set of all categories. Detection of a unit does not imply that the decision rule is able to identify the unit as specifically belonging to one particular category.
Dielectric Constant:	Electrical property of a matter that influences radar returns; also referred to as complex dielectric constant.
Diffuse Reflection:	The type of reflection obtained from a relatively rough (in terms of wavelength of the EMR) surface, in which the reflected rays are scattered in all directions.
Doppler Effect:	A change in the observed frequency of EM or other waves caused by relative motion between the source and the observer.
Emission:	With respect to EMR, the process by which a body emits EMR usually as a consequence of its temperature only.

Emissivity: The ratio of the radiation given off by a surface to the radiation given off by a blackbody at the same temperature; a blackbody has an emissivity of 1, other objects range between 0 and 1.

Fiducial Marks: Index marks (usually 4), rigidly connected with the camera lens through the camera body, which forms images on the negative. The marks are adjusted so that the intersection of lines drawn between opposite fiducial marks defines the principal point.

Field of View: The solid angle through which an instrument is sensitive to radiation. Owing to various effects, diffractions etc., the edges are not sharp. In practice they are defined as the "half-power" points, i.e., the angle outwards from the optical axis, at which the energy sensed by the radiometer drops to half its own axis value.

Frequency: Number of oscillations per unit time or number of wavelengths that pass a point per unit time. The frequency bands used by radar (radar frequency bands) were first designated by letters for military secrecy. Those designations are:

Frequency band	Approximate frequency range, gigahertz	Approximate wavelength range, centimeters
P-band	0.225 to 0.39	140 to 76.9
L-band	0.39 to 1.55	76.9 to 19.3
S-band	1.55 to 5.20	19.3 to 5.77
X-band	5.20 to 10.90	5.77 to 2.75
K-band	10.90 to 36.00	2.75 to 0.834
Q-band	36.00 to 46.00	0.834 to 0.652
V-band	46.00 to 56.00	0.652 to 0.536

The C-band, 3.9 to 6.2 gigahertz, overlaps the S- and X-bands. The letter designations have no official sanction, but are still widely used.

Gain:	(1) A general term used to denote an increase in signal power in transmission from one point to another. Gain is usually expressed in decibels. (2) An increase or amplification.
Ground Range:	The distance from the ground track (nadir) to a given object.
Ground Resolution Cell:	The area on the terrain that is covered by the instantaneous field of view of a detector. The size of the ground resolution cell is determined by the altitude of the remote-sensing system and the instantaneous field of view of the detector.
Ground Track:	The vertical projection of the actual flight path of an aerial or space vehicle onto the surface of the earth or other body.
Illumination:	The intensity of light striking a unit surface known as the specific illumination or its liminous flux. It varies directly with the intensity of the light source and inversely as the square of the distance between the illuminated surface and the source. It is measured in a unit called the lux. The total illumination is obtained by multiplying the specific illumination by the area of the surface covered by the light. The unit of total illumination is the lumen.
Instantaneous Field of View (IFOV):	A term specifically denoting the narrow field of view designed into detectors, particularly scanning radiometric systems, so that, while as much as 120° may be under scan, only EMR from a smaller area is being recorded at any one instant.
Irradiance:	The measure, in power unit, of radiant flux incident upon a surface. It has the dimensions of energy per unit time (e.g., watts).
Irradiation:	The impinging of EMR on an object or surface.

Look Angle (radar):	The direction of "look", or direction in which the antenna is pointing when transmitting and receiving from a particular cell.
Look Direction:	Direction in which pulses of microwave energy are transmitted by a SLAR system. Look direction is normal to the azimuth direction. Also called range direction.
Nadir:	(1) The point on the celestial sphere vertically below the observer, or 180° from the zenith. (2) That point on the ground vertically beneath the perspective center of the camera lens.
Noise:	Random or regular interfering effects in the data which degrade its information-bearing quality.
Passive System:	A sensing system that detects or measures radiation emitted by the target.
Pitch:	Rotation of an aircraft about the horizontal axis normal to its longitudinal axis, which causes a nose-up nose-down attitude.
Polarization:	The direction of vibration of the electrical field vector of electromagnetic radiation. In SLAR systems polarization is either horizontal or vertical.
Pulse:	(1) A variation of a quantity whose value is normally constant; this variation is characterized by a rise and a decay, and has a finite duration. (2) A short burst of EMR transmitted by the radar.
Reflectance:	The ratio of radiant energy reflected by a body to that incident upon it. The suffix (-ance) implies a property of that particular specimen surface.
Reflection (EMR Theory):	EMR neither absorbed nor transmitted is reflected. Reflection may be diffuse when the incident radiation is scattered upon being reflected from the surface, or specular, when all or most angles of reflection are equal to the angle of incidence.

Resolution:	The ability of an entire remote sensor system, including lens, antennae, display, exposure, processing, and other factors, to render a sharply defined image. It may be expressed as line pairs per millimeter or meter, or in many other ways. In radar, resolution usually applies to the effective beamwidth, often defined as the half-power points. For infrared line scanners the resolution may be expressed as the instantaneous field of view. Resolution may also be expressed in terms of temperature or other physical properties being measured.
Resolution Cell:	The smallest area in a scene considered as a unit of data. For Landsat 1 and 2 the resolution cell approximates a rectangular ground area of 0.44 hectares or 1.1 acres.
Roll:	Rotation of an aircraft about the longitudinal axis to cause a wing-up or wing-down attitude.
Scan Line:	The narrow strip on the ground that is swept by the instantaneous field of view of the detector in a scanner system.
Scattering:	(1) The process by which small particles are suspended in a medium of different index of refraction diffuse a portion of the incident radiant in all directions. (2) The process by which a rough surface reradiates EMR incident upon it.
Signal to Noise Ratio:	The ratio of the level of the information-bearing signal power to the level of the noise power. Abbreviated as S/N.
Slant Range:	For radar images this term represents the distance measured along a line between the antenna and the target.

Spectral Reflectance:	The reflectance of electromagnetic energy at a specific wavelength interval.
Specular Reflection:	The reflectance of electromagnetic energy without scattering or diffusion, as from a surface that is smooth in relation to the wavelengths of incident energy.
Swath Width (total field of view):	The overall plane angle or linear ground distance covered by a multispectral scanner in the across-track direction.
Target:	(1) An object on the terrain of specific interest in a remote sensing investigation. (2) The portion of the earth's surface that produces by reflection or emission the radiation measured by the remote sensing system.
Vignetting:	A gradual reduction in density of parts of a photographic image caused by the stopping of some rays entering the lens.
Wavelength (symbol):	Wavelength = velocity/frequency. In general, the mean distance between maxima (or minima) of a roughly periodic pattern. Specifically, the least distance between particles moving in the same phase of oscillation in a wave disturbance. Optical and IR wavelengths are measured in nanometers (10^{-9} m), micrometers (10^{-6} m) and angstroms (10^{-10} m).
Yaw:	Rotation of an aircraft about its vertical axis, causing the longitudinal axis to deviate from the flight line.

APPENDIX D

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REFERENCES

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Note: See Appendix B for annotations to references.